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STUDY TO EXPAND SIMULATION COCKPIT DISPLAYS OF ADVANCED SENSORS

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FINAL REPORT FOR PERIOD 6 OCTOBER 1979 - 6 OCTOBER 1980

[redacted]

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This contractual effort was directed to the study to determine, examine and evaluate the cost and effectiveness of alternate methodologies for providing simulation capabilities of airborne sensor displays likely to be operational on combat aircraft throughout the 1980's and early 90's at levels of fidelity appropriate to R&D in flight simulation at the Flight Dynamics Laboratory

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20. ABSTRACT - continued

This study examined the state of the art and the projected technology of sensor systems adaptable to the combat aircraft engaged in threat environment in varied atmospheric weather conditions in dawn, dusk, night and day light.

Some of the advanced sensor systems which were the focus of attention are the Low Altitude Navigation and Targeting Infra Red system for Night (LANTIRN), Target Acquisition/Designator System (TADS), Pilot Night Visual System (PNVS), and Multispectral Target Cuing (MYSTIC). These systems employ some technology of Low-Light Level Television (LLLTV), Forward Looking Infrared (FLIR), Synthetic Aperture Radar (SAR), and Laser Radar.

The methodologies of simulating these sensor systems and integrating them to the out-of-the-cockpit image generation systems available at FDL for full mission environment were investigated and recommendations addressing the future additions to and modifications of the facilities at FDL were presented.

The result of this study should enable the Flight Dynamics Laboratory to decide what further effort should be expended in the area of visual and sensor display as part of the 5-year plan for expansion and improvement of engineering R&D in flight simulation capability.

PREFACE

This final report covers the work accomplished during the period October 1979 - October 1980 under the Contract F33615-79-C-3621 entitled, "Study to Expand Simulation Cockpit Displays of Advanced Sensors." This work was supported by the Air Force Flight Dynamics Laboratory, AFSC, Wright-Patterson AFB, Ohio 45433, and was accomplished under the program direction of V. Faconti.

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SUMMARY

In many airborne scenarios, the use of sensors to aid and expand the ability and effectiveness of the flight crew has become of prime interest. The Flight Dynamics Laboratory (FDL) is deeply concerned with the evaluation of innovative concepts in flight control and consequently has defined a need for a simulation facility which supports experiments in this area.

There are many sensors and technologies emerging which might influence flight and mission control. The myriad of possibilities must be simulated effectively by providing capabilities in major areas and then allowing sufficient flexibility to tailor the simulation to specific experimental and mission requirements.

The pilot is recognized as an integral part of the total flight control system and FDL is actively involved in experiments to integrate and correlate new system technologies which result in crew workload reductions. FDL's simulation facility must therefore be responsive to the sensor related advancements in flight technology.

This study, then, examines the advanced sensor simulation requirements at FDL and proposes solutions which lie within the constraints of available technology and the Statement of Work (SOW).

A simulator facility allows rapid design and execution of experiments which, in the real world, might cause costly hardware changes or dangers to crew members. The simulation also allows the introduction or exclusion of factors which may focus the experiment more clearly on specific sensor-associated areas of interest.

In order to arrive at simulation hardware configurations and system specifications, it is necessary to examine the types of sensors and the mission environments which are of concern to FDL. These areas of interest are defined in the 5-Year Plan and include the following sensors: television (TV), low-light-level TV (LLLTV), infrared (IR), forward-looking IR (FLIR), forward-looking radar (FLR), synthetic aperture radar (SAR), and laser radar.

Sensors fall into two general categories: radar devices and electro-optical (E-O) devices*. In the first category, only airborne radars were considered in light of FDL requirements. The study notes that although changes are taking place, the technology is mature and no fundamental changes are expected in the near future. What is expected are changes in processing capability and automation as a function of improvements in on-board and dedicated processing capabilities. The major implication is that as radar becomes more digitally oriented and as computer symbology and decision making becomes more extensive, the digital radar simulation techniques become more feasible. Existing analog radar simulation devices can be used to give interim capability until the cost and acquisition burdens of a more sophisticated system can be overcome.

Electro-optical sensors have been the target of more technical activity and advancements which will affect simulation. The simulation will have to respond to varying fields of view, to various resolutions, and to many different sensor signatures. When atmospheric and weather attenuations are added, the simulation problems become extremely complex. Only a digital image generator

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*Technically, there is a third category of far infrared (FIR) sensors operating at wavelengths beyond 30 micrometers; however, these sensors can be simulated by the same techniques used for E-O sensors.

has the flexibility to handle all of these problems and still provide a real-time interface to flight-control. Again, existing hardware can be used to gain interim capability through judicious modifications.

Two programs sponsored by FDL are typical examples of sensor-oriented research and the type of missions concerned. The Integrated Flight/Fire Control (IF/FC) program and the Integrated Flight/Weapon Control (IF/WC) program both use sensor derived data (electro-optical sensor/tracker) to enhance flight maneuvers for better accuracy in weapons delivery. The Low Altitude Navigation and Targeting Infrared System For Night (LANTIRN) is another example of mission and hardware requirements which this simulation must support. LANTIRN is an advanced system combining low-level, night, and adverse navigation with target acquisition and weapons delivery. A wide field-of-view IR sensor is employed for navigation with a narrow field-of-view capability for target acquisition weapon delivery. Other advanced sensor systems like Target Acquisition Designation Sight (TADS) and Pilot Night Vision Sensor (PNVS) provide the aircraft pilot/gunner with day, night, and adverse weather target acquisition capability by means of direct view optics (DVO), day television (DTV) and FLIR sighting subsystems need to be simulated.

In general, the requirements for sensor systems lie in the following areas:

- o Reconnaissance
- o Navigation
- o Target Acquisition
- o Fire Control
- o Weapon Guidance

with major emphasis on crew survival and effectiveness.

The simulation facility must support not only current programs, but must contain sufficient flexibility to accommodate new

developments throughout the next decade and support the eventual goal of total mission simulation.

In order to obtain simulation capabilities at a reasonable cost and in a reasonable time, the bounds of current technology must not be exceeded. Only three types of image generators meet these requirements. These are the camera model system, the digital image generator (DIG), and film or video tape systems. The study examines each in detail and concludes that the DIG is the preferred solution.

However, the existence at FDL of simulation hardware such as camera models systems (MS) and a T-10 analog radar landmass simulator (ARLMS), along with acquisition costs and time, create restrictions which affect the selection and performance of new hardware. The study proposes a modification program to gain interim capability through the use of existing CMS's. Although these systems are inherently limited in gaming area, resolution, and field of view, certain sensor-related missions can be simulated. It is necessary to limit performance to specific corridors and to rather large fields of view (<15°), but with the addition of analog video processing, certain sensors (such as the LANTIRN navigation requirements) can be effectively simulated.

The T-10 analog radar landmass simulator is not easily changed, but because of the cost of a digital system, modifications must be considered. It is well known that the United States Air Force is actively involved in a similar T-10 upgrade program. This study considers the desired goals of that program and recommends that FDL take advantage of developments under this contract.

Finally, the study concludes that the long-term goals cannot be met by up-grading existing hardware. Attainment of the ultimate goals of simulation fidelity, total mission simulation, and

real-time interface to advanced flight-control hardware, requires the acquisition of new advanced simulation hardware. The characteristics of the recommended hardware are given along with cost considerations and facility impact.

In recognition of the many factors, a multi-step approach to upgrading the sensor simulation at FDL is recommended. Such a plan will provide useful capabilities over the interim period during which funding and new hardware will be obtained.

The sequential approach would modify the existing camera-model systems to gain IR and TV capability, modify the existing T-10 ARLMS, and start acquisition procedures for a digital facility.

A total modernization of the FDL facility should be considered as a long-term goal. The emerging sensor technology provides a much higher capacity for information than current systems and simulation of these systems will demand new approaches that reach beyond the practical and often theoretical limits of current or even upgraded FDL equipment. The new equipment will include an all-digital approach to sensor simulation with a computer image generation (CIG) and a digital radar landmass simulator (DRLMS) as the major elements. This approach is the most technically sound, and provides the flexibility and expansion capability to stay abreast of sensor technology.

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1.0 INTRODUCTION

The Engineering Simulation Group of FDL plans and conducts ground-based engineering simulations for the purpose of design evaluation and refinement of advanced aircraft concepts and flight control technologies under realistic mission-task environments. In 1978, to maintain continued advancement in the development of engineering flight simulation, FDL prepared a long-range plan for updating the engineering simulation laboratory to keep pace with changes in flight control technology. One of the primary considerations of this long-range plan was the need for expanded capabilities to facilitate simulation of advanced sensor displays, a technology which is emerging in response to the significant potential of advanced sensors in certain tactical airborne scenarios. Applicable sensors include television (TV), low-light-level TV (LLLTV), infrared (IR), forward-looking IR (FLIR), forward-looking radar (FLR), synthetic aperture radar (SAR), electro-optical scanner trackers, laser radar, etc. The objectives of this study are to define, examine, and evaluate alternative approaches for simulation of those sensor displays which are likely to be integral to FDL research in the next decade.

1.1 SCOPE OF STUDY

Link Flight Simulation Division of The Singer Company has performed a study which systematically examines the major elements of providing airborne sensor display simulation capabilities. These elements include not only sensors and their capabilities throughout the 1980's and early 1990's, but also the associated mission requirements and state-of-the-art (SOTA) simulation technology.

The performance parameters of each study element were evaluated and compared in an effort to reduce the possibilities to viable systems concepts.

Mission requirements were examined only to the level of detail necessary to define simulation hardware. The suggested concepts are not based on any specific mission details, but try to meet the generic and varied experimental requirements of FDL.

Although the scope of this study does include cockpit displays, the primary effort concerns the image generator. Display technology is mature and changes are slow in the cockpit environment. In fact, display format and crew workloads are subjects of experiments which this hardware must support. In order to allow the freedom necessary for these experiments, this study considers cockpit display devices only in general terms.

1.2 REPORT FORMAT

The format of this report follows the chronological progression of research required to complete the study objectives. This format was selected to provide firm documental backup for the proposed recommendations and, further, to establish a foundation which reflects the scope of the current endeavor and upon which FDL can base decisions for additional research and investigations.

It is important to acknowledge that sensor simulation is an emerging technology and as such has appeared with little definition to encompass a seemingly endless array of actual and conceptual sensor devices and utilizations. Consequently, it has been necessary to constrain the scope of this study in order to allow concentration on the development of useful and realistic recommendations. This has been accomplished by determining a set of simulation requirements based on formal projections of FDL's sensor utilization and predicted characteristics of the sensors involved.

As an initial step in determining utilization requirements, the first section of this report considers the user, primarily

through examination of FDL's "Plan for Improvement of Engineering Flight Simulation Capability" (FY 79 to 84), herein referred to as the 5-Year Plan. Summarized in the 5-Year Plan are FDL's objectives and scope regarding sensor simulation, existing equipment, current sensor capabilities and limitations, simulators with projected sensor requirements, associated mission requirements, key sensor issues, and related concepts associated with FDL's long-range plans.

Although missions are briefly discussed in the 5-Year Plan Analysis, a separate report section is included (Section 4.0) which expands on the sensor-oriented mission segments which are expected to be encountered in the Engineering Simulation Laboratory. This section is derived from numerous sources, including FDL's 5-Year Plan, FDL's Total Mission Steering Group directives, FDL Mission profiles developed for the Logicon DIG study, current mission-oriented technical reports and articles, and mission projections received from sensor vendors. Section 4.0 develops sensor simulation requirements dictated by the anticipated missions. These requirements include the applicable sensors, the tactical environment (gaming area, targets, threats, etc.), and the physical environment (terrain, weather, smoke, etc.). Also delineated are requirements associated with the engineering aspects of the mission simulations, such as air-to-ground weapon delivery accuracies and hit indications.

Section 3.2 provides additional detail about the simulation requirements by determining those requirements which are dictated by the applicable sensors. This section summarizes the state of the art of the various sensor types, notes the associated parameters, and provides quantitative values representative of actual or anticipated systems.

The combination of mission and sensor-oriented requirements constitutes, in effect, a specification scope which encompasses

FDL's projected sensor simulation needs. All sensor simulation approaches presented in this report have been developed within this scope. Each approach represents varying degrees of sophistication, cost, and utility within the specified scope.

Before the discussion of feasible simulation approaches, an intermediate section (Section 5.0) is included which analyzes the state of the art of those simulation technologies which have been considered in this study for their potential in sensor simulation. Included are camera-model systems, laser image generators, film or tape systems, Defense Mapping Agency, Aerospace Center (DMAAC) data, video processing, DIG, radar simulation, and electronic countermeasures (ECM) simulation. Analysis of this section, in comparison with the developed simulation requirements, should readily show why each recommended approach has been included in this report and why certain possible approaches have not been recommended.

Section 6.0 discusses two proposed sensor simulation approaches. The first approach would use existing or modified FDL equipment. The second approach would require supplemental equipment. Parametric and cost comparisons are subsequently provided.

2.0 STUDY METHODOLOGY

The general approach to the study is shown in Figure 2.0-1. Data was gathered from five major sources and subsequently analyzed to satisfy the major objectives of the study.

In order to define the sensors and the tactical environment in which they operate, an extensive literature search was conducted. Both vendor and user agencies were contacted to gain further understanding of current equipment and its useage. These contacts also provided data on future trends of sensor equipment and mission scenarios.

Once the sensor characteristics were known and the mission requirements were determined, the state of the art of simulation was analyzed for applicable technology. The net results are a statement of the simulation problem and a description of available simulation hardware, its capabilities, and future potential.

As part of the data gathering process, the study also examined the specific simulation requirements of the Flight Dynamics Laboratory and the existing inventory of equipment. The study then developed alternative plans to modify existing software and hardware at the Engineering Flight Simulation Facility and identified additional equipment necessary to simulate the major capabilities and characteristics of the sensor displays of importance to the human operator.

This was accomplished by making parametric comparisons of various simulation approaches and then combining those into various system configurations which meet the necessary sensor requirements and simultaneously attempt to use existing hardware to maximum advantage.

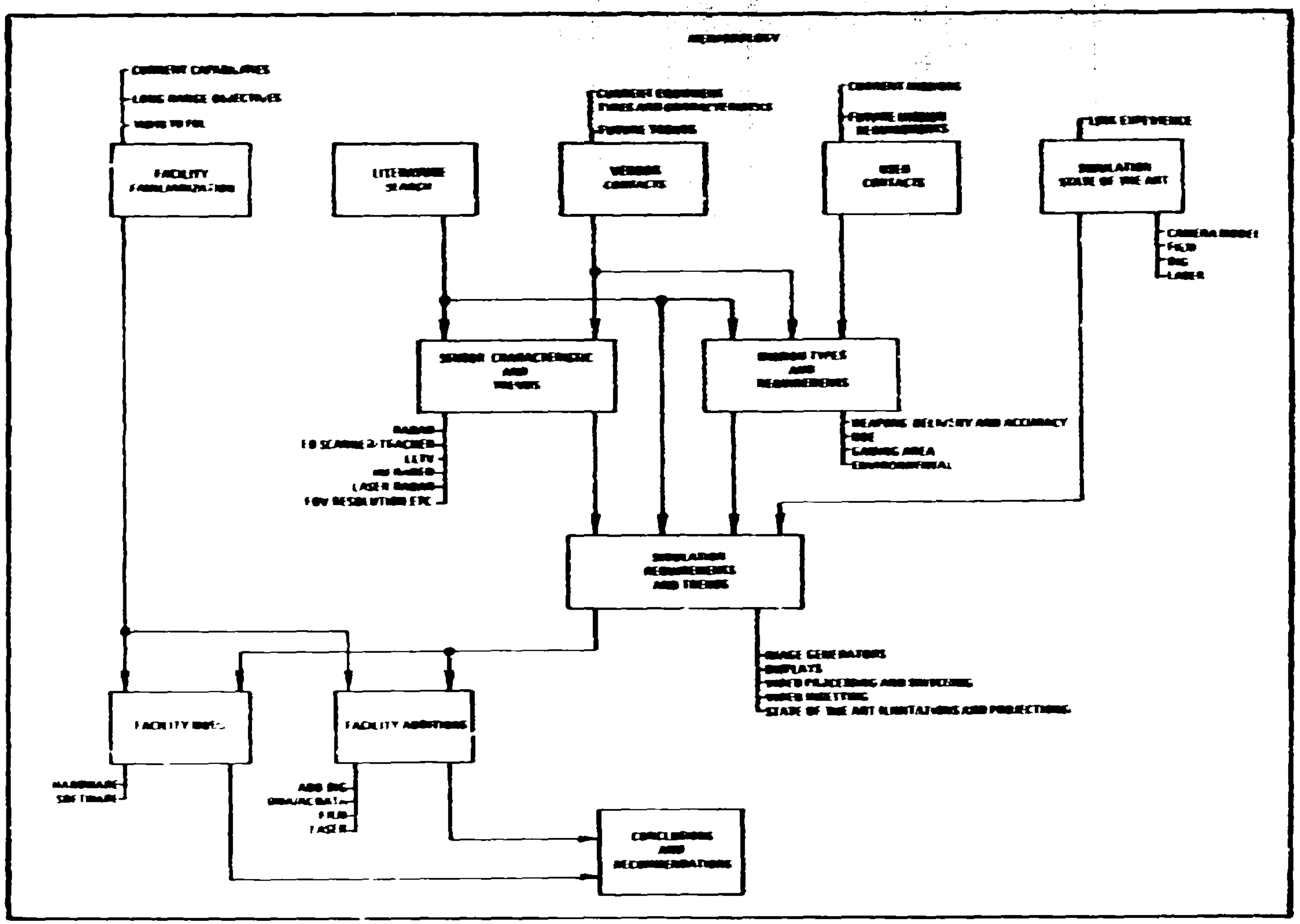

Figure 2.0-1 GENERAL APPROACH

In summary, the study presents the most viable solutions in greater detail and makes recommendations for the most cost-effective system approaches.

3.0 STUDY DETAILS

3.1 DATA ACQUISITION

3.1.1 Facility Familiarization.

Real-time man-in-the-loop flight engineering simulation is a closed-loop technology coupling the designer, the simulated system, and pilots so that conceptual systems may be evaluated and refined prior to the development of full-scale aircraft systems. Significant cost and time savings are realized when a concept can be evaluated in an engineering simulation prior to integration in a host aircraft. This is especially obvious when one considers that numerous minor modifications to the original concept may be readily accommodated in an engineering simulator whereas small changes to an aircraft system might easily require a major system redesign. Another advantage of engineering simulation is the versatility afforded the designer in relation to environment, both physical and tactical. Desired environmental factors can be included and varied on a test-by-test basis. Undesirable factors, which may be uncontrollable in real-world evaluations, may be conveniently left out of a simulation. The primary drawback and main challenge of simulation is the limit to the amount of realism which can be created, both in terms of the conceptual system and the environment in which its operation is ultimately intended. Each simulation requires a balance between the higher costs associated with increased levels of realism and the amount of representative realism required to make the simulation believable to the pilot. Engineering simulations can be beneficial only when they are realistic enough for the pilot to react essentially the same as he would under real-world conditions.

FDL performs man-in-the-loop engineering simulations to evaluate various innovative concepts, including flight control technology. The association of advanced sensors to flight control

technology may not be obviously apparent; however, the relationship can be indirectly traced. In past years the focal point of integrated aircraft system operation has been the pilot (or the crew). For example, a tactical pilot, having received extensive training in the capabilities and limitations of his aircraft's basically independent flight and weapon subsystems, would fly his aircraft in a manner which, in his judgement, would most effectively complement the capabilities of the weapon system. Of course, in combat situations (especially in dense threat environments) this would be only one of numerous, almost simultaneous judgments required of the pilot. FDL is dedicated not only to optimizing flight control systems but also to optimizing their use.

Accordingly, it has long been recognized that the pilot is an integral component of flight control technology. Extensive studies have been conducted by FDL in efforts to reduce pilot workload so that the total effectiveness of the integrated pilot-aircraft system could be increased. Due to the closed-loop nature of engineering simulation and FDL's associated responsibilities in generating flight control specifications, many of the results of these studies are now being incorporated in new aircraft subsystem designs. On a larger scale it may be stated that research by FDL and similar institutions has resulted in a new philosophy in military aircraft development, wherein subsystems which used to be designed (specified) independently to be optimized for their individual roles, are more and more often designed with the complimentary subsystem technologies in mind so that one optimum total aircraft results. A significant factor contributing to the feasibility of this philosophy has been the enormous advancements made in digital technology, especially in circuit miniaturization and computational speeds. These advances are allowing the incorporation of increasingly sophisticated electronic packages (including high-capacity on-board computers and advanced sensors) in the same restricted airframe space previously filled by bulkier and less capable generations of electronics. Interdependently designed sub-

systems are rapidly evolving into integrated subsystems. An example of an integrated design would be a flight control system, designed with the weapon system capabilities in mind, but also designed to receive real-time inputs from the weapon system which would directly affect the operation of the flight controls under certain conditions. In essence, an important aspect of the state of the art of applied flight control technology is the correlation and integration of complementary technologies. FDL is actively involved in evaluating methods to exploit expanded computational capabilities and integrated system techniques.

Two programs currently being sponsored by FDL are typical of the sensor-oriented research that can be anticipated in the engineering simulation laboratory and also clearly illustrate the association of sensors and advanced flight control technology. The Integrated Flight/Fire Control (IF/FC) program and the Integrated Flight/Weapon Control (IF/WC) program both evolved from the recently developed Firefly fire control concept. Under this concept, information derived from advanced electro-optical sensor trackers is fed via a fire control computer to the aircraft's autopilot/flight control system to maneuver the fighter more accurately into firing position. Simulations of the Firefly concept have shown significant increases in hit probability and aircraft survivability. The IF/FC program (using unguided weapons) and the subsequent IF/WC program (using guided weapons) both seek to investigate the improved combat effectiveness possible through integration of the flight and fire control (weapon) systems. The use of flight simulators readily allows comparison of manual, semi-automatic, and fully automatic operations in a dense threat environment.

FDL's engineering simulation laboratory must develop advanced sensor simulation capabilities so that the facility can be responsive to the sensor-associated advancements which are emerging in flight control technology.

Equipment currently at FDL's simulation laboratory can be divided into three categories: computers, simulators, and simulator complementary systems, including hardware to facilitate visual and radar simulations.

For the purpose of this study it is assumed that FDL's flexible complement of analog and digital computers can quite readily accommodate any main frame software requirements associated with the recommended approaches to sensor simulation. This assumption is readily justified on the basis that this study is primarily involved with the evaluation of dedicated video sources (modelboards, DIG, etc.) which generally require only minimal interface support from the main simulation computer system. Moreover, sensor-associated simulations which are recommended as software implementations (e.g., electronic warfare (EW) environment) are of the type which may be applied with more or less sophistication for each simulation (requiring more or less computer space) as dictated by the associated engineering team's interpretation of the sensor's relative importance in relation to other areas of the total simulation design.

Existing FDL simulators include a multi-crew transport/bomber on a three-degree-of-freedom motion base, a side-by-side two-place fighter/bomber (F-111 equivalent) on a five-degree-of-freedom motion base and the Large Amplitude Multimode Aerospace Simulator (LAMARS) which allows large-amplitude motion cuing in five-degrees-of-freedom. Relevant limitations noted in the 5-Year Plan are the very limited displays in the fighter/bomber, and the lack of a tandem cockpit in the LAMARS. FDL also has time-shared access to the Avionics Laboratory's (AL) Digital Avionics Information System (DAIS) close-air support cockpit. As part of the 5-Year Plan, moreover, FDL intends to develop, by 1984, an Advanced Fighter Station (recently redesignated as the Total System Integration Simulator (TSIS)) which will allow single and tandem simulations and will include advanced multiplexed displays and a large field-of-view visual system.

Existing FDL complementary simulation hardware includes an American Airlines/Redifon rigid model visual system with an associated duoview display projection system; the LAMARS visual system including sky/earth projector, camera-model target generator, and target projector; an early generation General Electric computer image generator (CIG) system; and an analog/digital radar landmass simulator.

Modelboards are of two different scales: a 5000:1 scale, covering 12.3 by 37.8 nmi with an altitude range of 100-20,000 ft; and a 1500:1 scale detailed airport blow-up from the 5000:1 board, covering 3.7 by 11.7 nmi with an altitude range of 12-3000 ft. In anticipation of modelboard use in sensor simulation, FDL has contracted the DMAAC to draw up topographical maps and create digital data bases (DDB) for both modelboards. It should be noted, however, that DMAAC is only developing elevation data bases and is not creating feature or cultural files, although the cultural file is a possible add-on item. Thus data will be available for terrain following (TF) and terrain avoidance (TA) simulations but data will not be available for correlated DIG generation of detailed sensor imagery.

FDL's existing terrain model system has no moving targets and has a limited dive angle capability due to restricted pitch excursions (25° to -48°) in the probe mechanisms. Also, it should be noted that the pointing accuracy and position repeatability of the present probe is much poorer than the probe capabilities available in state-of-the-art systems. The 5-Year Plan recommends procurement of an accurate high-pitch angle probe; however, the price of such a system has been prohibitive. FDL recognizes the need for an accurate probe to facilitate meaningful air-to-surface weapons delivery studies and accordingly is still actively seeking to procure such a device. The camera system associated with terrain models is simultaneous, 3-channel color and operates on a

625-line European video standard. It is being converted to operate as a 60-hertz 525-line color or 1000-line black and white system.

A relevant subsystem of the LAMARS visual equipment is the physical model target image generator which includes a camera system imaging on a gimballed aircraft model, the combination of the two producing a target for air-to-air simulations. Currently the model is mounted in a lucite sphere which tends to slip, producing tracking errors under highly dynamic maneuvers. The 5-Year Plan indicates intended procurement of a state-of-the-art gimbal system.

As part of the 5-Year Plan, FDL is analyzing the state of the art of CIG systems and plans to procure an advanced system. A relevant aspect of FDL's analysis is the capability of advanced CIG's to provide sensor simulations.

FDL's existing radar landmass system consists of generalized radar software coupled with a Singer-Link F-111A tri-color plate analog landmass. However, this system does not include the electronics required for the original F-111A radar landmass capabilities of TF/TA.

As clearly stated in the 5-Year Plan and further evidenced by sponsorship of this study, FDL has virtually no existing capabilities for advanced sensor simulation. The only equipment which could be considered as representing a sensor capability is the radar landmass simulator. However, the operational characteristics of the decade-old analog portion falls far short of being adequate to simulate the performance of state-of-the-art radar systems, especially with the added consideration that the original terrain avoidance and terrain following features are not available.

A pseudo-sensor simulation capability which may be made available to FDL on a short-term basis is the CIG/DAIS visual sensor simulator. This low-cost system developed for DAIS by Technology Incorporated uses analog video processing techniques to generate representative sensor imagery from a terrain board video signal. Employing such techniques as video bandwidth reduction, edge enhancement, noise summation, and linear and nonlinear transfer functions, this system is capable of pseudo-simulating LLLTV, FLIR, FLR, and SAR. The original video signal can also be used for an out-the-window visual display. The main drawback of the DAIS visual sensor simulator is that it provides representative imagery, not actual target signatures (i.e., IR and/or microwave). Without the capability for proper target signatures (especially IR hot spots), FDL does not consider such a system adequate for its long-term sensor simulation requirements.

As an aid in directing the scope of this study, several specific questions were generated which sought to refine FDL's simulation requirements. Subsequently, excerpts were collected from the 5-Year Plan which related to each question. Each group of excerpts was then collectively assessed. The remainder of this section documents those assessments. The analysis was performed in relation to each of the following questions: On what type or types of aircraft will FDL be required to perform sensor simulations? What types of missions will be involved? What will be sought to be proven in these simulations, or as stated in the 5-Year Plan, what are the issues? What is the time frame for implementation? Also, in the performance of this analysis, various independent statements were noted which were deemed pertinent to this study; these are also discussed.

Table 6 of the 5-Year Plan summarizes a survey made by FDL of potential users of the engineering simulation laboratory. Four of the potential simulations included a requirement for sensor displays. Of these, three were specifically designated for the

forthcoming TSIS cockpit. The fourth, called IF/FC, is assumed to refer to a program similar to the earlier IF/FC and IF/WC programs, both of which are associated with fighter aircraft. The 5-Year Plan's subsequent analysis of trends in aircraft, as related to simulation capability readiness, includes sensor applications in all three basic classifications of fighter aircraft -- close-air support, tactical strike, and air superiority. The only implication of sensor-oriented research on another aircraft type is the mention of long-term studies for bomber penetration and survival. As indicated in Section 4.0 of this report, however, penetration and survival are also anticipated elements of required fighter missions. Considering this fact and the fact that fighter flight parameters (speed, pitch rates, etc.) are more demanding on simulations than those of bombers, this report assumes that sensor simulations recommended for fighter penetration and survival research can be readily applied to bomber research. Since FDL does not appear to have unique sensor simulation utilization requirements for transports or bombers, the requirements and subsequent recommendations developed in this report are keyed to fighter aircraft.

In considering FDL's anticipated use of its simulators, a relevant point is that FDL has designated the TSIS as the focal point for eventually correlated visual and sensor simulations.

A central theme of FDL's 5-Year Plan is the eventual development of a total mission simulation capability. However, "emphasis has been placed on the air-to-surface task capability due to the general lack of precision capability to perform this task. . . . . and increased importance of the design factors for near term aircraft and subsystems design". The various segments of a typical air-to-surface mission include takeoff, cruise, penetration, weapons delivery, aerial refueling, and return and landing. Of these segments, penetration and weapons delivery represent the primary areas of sensor augmentation in advanced mission concepts.

Research in night and all-weather penetrations will require simulation capabilities for LLLTV, FLIR, and TF/TA radar. Conventional and unconventional weapons delivery studies, including target acquisition and identification, will require simulation of SAR, TV, LLLTV, and FLIR, along with TV and IR weapons.

FDL also seeks to enhance its air-to-air simulation capabilities. Potential sensor complements include forward-looking multimode radar, FLIR, and TV (possibly with zoom capabilities). These sensors are of particular interest in certain critical tasks associated with engagement maneuvers including acquisition, identification, tracking, and weapons delivery.

Simulation requirements for Radar Homing and Warning Systems (RHAWS) capabilities are pertinent to both the air-to-surface and air-to-air tasks anticipated at FDL.

Total mission capability also requires total mission environment. Natural environmental factors required to accompany sensor performance simulations include the proper electromagnetic representation of terrain imagery, variable weather effects including signal attenuations, and sun effects including time-of-day, time-of-year, and sensor blinding. Required tactical environmental factors include friendly and threat gunfire and missiles, smoke, targets, hit indications, and electronic warfare activity. Again, proper electromagnetic representations are necessary. It should be noted that FDL desires to augment mission capabilities with multiple moving surface targets.

The simulation of individual sensor operational characteristics is also essential to ensure mission fidelity.

The preceding paragraphs only summarize the various aspects of anticipated FDL sensor oriented missions. Section 4.0 provides an expanded definition of the specific sensor simulation requirements dictated by expected FDL mission scenarios.

The 5-Year Plan mentions two key issues in association with the requirement for advanced sensor simulation. The first is that of sensor-aided versus visual weapons deliveries. This issue indicates that mission simulations are planned not only to assess adverse weather and night operations but also to optimize conventional and unconventional daytime weapon deliveries. The FDL-sponsored IF/FC and IF/WC programs are indicative of such research. In light of this issue, two desirable factors in a sensor simulation approach are the ability for and ease of correlation with an out-the-window visual scene.

The advent of advanced sensors in tactical aircraft throws a new twist into the ever controversial debate over one-man versus two-men crew stations. On the surface it appears that the incorporation of such advanced technologies would lessen the need for a second crew member. However, on the other hand, it is quite probable that added capabilities in the dimensions of performance and survivability could be exploited to an even greater degree in a two-man cockpit. Tandem cockpits with separate sensor displays place varying requirements on the sensor simulation depending on the desired configuration. If it is desired that one display only repeat the display of the other cockpit then the only additional requirement for supplying sensor imagery to the second cockpit is dedicated electronics to switch and drive signals from a common video source. To provide different sensor displays to each cockpit, with common controls (ie. only one crewmember at a time can adjust controls such as thresholding) requires independent video sources (or independent sensor processing channels if a common source is being used for multiple sensor types). If independent displays and controls are desired then two independent video sources or sensor processing channels are required for each sensor type. Thus two additional desirable factors in a sensor simulation approach are the capability to generate multiple sensor images from one source and the capability for parallel channel operation.

Simulation associated with these key issues will be performed not only in relation to assessing mission task performance but also in relation to survivability. Survivability is a mission factor which is receiving increased attention throughout the armed forces due to the continually increasing ratio of threat to friendly resources.

The 5-Year Plan calls for the following increased capabilities relevent to advanced sensor simulation:

<u>by FY80</u>

*Enhanced air-to-surface task (high-pitch angle visual probe, moving target)
*CRT displays for crew station evaluation

<u>by FY82</u>

*Advanced sensor displays and controls
*Broad gaming area; flexible CIG visual processing.

<u>by FY84</u> Total Mission Capability

*Air-to-air (two-vs-one)
*Air-to-surface (multiple moving target)
*Terrain following
*Variable weather

In relation to total mission capability, the 5-Year Plan includes this statement, "While the capability will exist for continuous mission evaluation from takeoff. . . . . to landing, most simulation programs will only involve mission segments or tasks." Thus a sensor simulation approach which is highly recommended for one mission segment (e.g., weapons delivery) should not be penalized simply because it cannot be practically integrated with another basically unassociated segment (e.g., takeoff).

In relation to the DAIS visual sensor simulator, the 5-Year Plan states, "It appears that, for the money, a system similar to that developed by DAIS would be acceptable for the near-term application planned in this facility. If a slewable sensor is desired, this method would allow correlation with the outside visual scene only when the sensor was pointed straight ahead." It should be noted that any sensor simulations economically designed to use common image pick-up source still suffer from this restriction. Such a deficiency will not present a radical problem for navigational and terrain following sensor displays since the area of interest in such presentations is along the aircraft flight path; however, it will seriously degrade capabilities for evaluation of integrated sensor weapons which provide a slewable image to the crew. Obviously, with the technology of such weapons, it will be desirable to test unconventional approaches which exploit the weapon's slewing capability as opposed to exposing the aircraft to the vulnerability of conventional straight-in deliveries. A similar problem arises with sensor zoom capabilities; however, in this case another trade-off is possible depending on the zoom mechanism employed. For example, a common visual and sensor image source could be used and the sensor display electronically zoomed; however, the resolution of the zoomed presentation could not be greater than that of the unzoomed image. If separate image sources were used, then high resolution zoom would be possible with opto-mechanical zoom. Figure 3.1.1-1 illustrates various visual/sensor presentation combinations feasible with common and separate image sources.

A specific goal of the 5-Year Plan is to "accurately program resources (dollars and manpower) to accomplish the expanded role of engineering simulation." Flexibility and growth are primary criteria in FDL procurements. State-of-the-art equipment is generally sought; however, FDL clearly recognizes the risk involved with premature selection of unproven developmental equipment. Accordingly, the emphasis in this study has been to seek out practical solutions using available technologies.

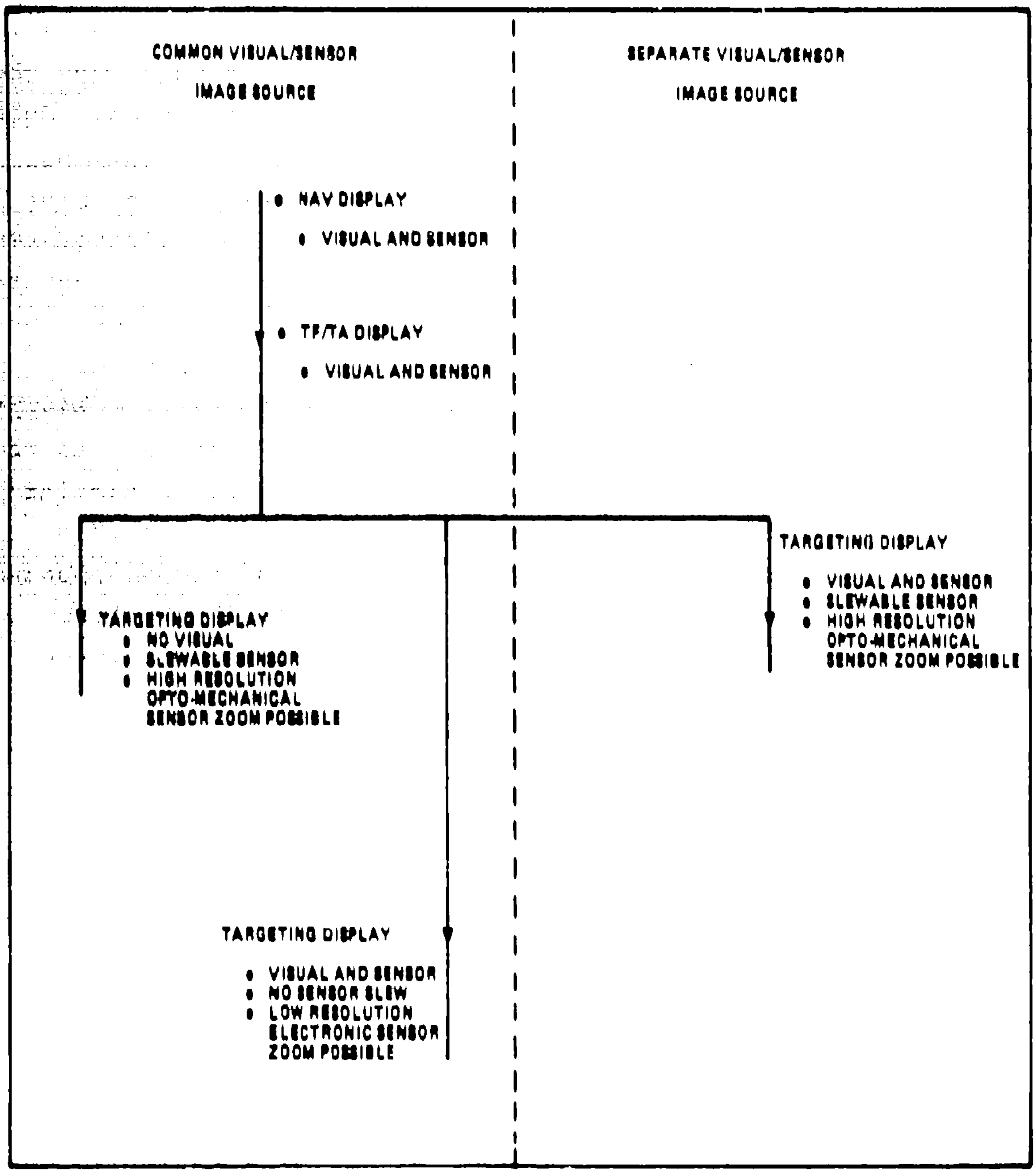

Figure 3.1.1-1 VISUAL/SENSOR PRESENTATION COMBINATIONS FEASIBLE WITH COMMON AND SEPARATE IMAGE SOURCES

3.1.2 Literature Search.

The bibliography later in this report lists military reports procured and reviewed in the course of this study. In addition, the review of approximately 200 issues of technical and military-oriented periodicals revealed innumerable articles, news reports, and advertisements which have provided valuable insight into current trends and advancements in state-of-the-art sensor technologies and sensor utilizations in military aircraft. Periodicals from which pertinent information was drawn include Aviation Week and Space Technology, Defense Electronics, Military Electronics/Countermeasures, International Defense Review, Interavia, Air Force, Electro-Optical Systems Design, Microwave System News, and Electronic Engineering Times.

3.1.3 Vendor Contacts.

To supplement the literature search, research personnel solicited information from numerous vendors of advanced sensor systems. We were very fortunate that several organizations agreed to meet with us to discuss various aspects of their fields of specialty.

The Electro-Optics Division of Texas Instruments Inc. (TI) provided a formal presentation on Thermal Image Processing. An important point emphasized by TI was that the resolution of aircraft thermal imaging systems is not expected to increase significantly from that of current systems. Although higher device resolution is feasible, there are several operational factors which limit useful resolution. The primary factor is aircraft vibration. To accommodate higher resolutions in military aircraft would require elaborate image stabilization or migration corrections to compensate for vibration effects. Other limiting conditions considered in TI's prediction of near constant resolution included atmospheric effects, system costs, and range of weapons (i.e., limit

on useful resolution). The primary thrust of development efforts, according to TI, is to enhance image processing so that pilot workload is reduced. In current systems, display image enhancement control, image interpretation, and reaction are functions which must be performed by an operator. The conflicting trends of decreasing available operator time (especially in high-speed, low-level flight) and increasing total sensor information capacity create a definite requirement for increased image processing capabilities. TI believes that many of the operator's functions can be automated in future E-O systems. Candidate functions include sensor control, display control, stabilization, target detection, target cuing, target recognition and classification, target ranging, track acquisition, target prioritization, platform control, and fire-control including weapons pointing. TI's presentation traced the continuing evolution of integrating operator functions into advanced electro-optical systems. It was noted that for many functions, the capability for total automation already exists. In the case of these functions, the major barrier to integration is component technology (i.e., the limits on how much electronics can be contained in a unit with a specified maximum weight and volume). Much emphasis is being placed on the development of digital scan conversion schemes since significantly greater processing capabilities per unit volume can be accomplished using digitized imagery. Image enhancement techniques are also being refined. The capability for automatic target detection and recognition and subsequently the subfunctions of target cuing, classification, prioritization, and acquisition, represent a primary area of research. Understanding the E-O image is a major barrier to the development of such functions. Currently, researchers are deeply involved in analyzing image data and developing algorithms which can be used to extract and identify targets from an image scene. Copies of TI's Thermal Image Processing presentation are contained in Appendix A.

Presentations made by Hughes Aircraft Electro-Optical Group were keyed to two of their existing developmental projects: Multi-Spectral Target Cuing (MYSTIC) and the Low Altitude Navigation Targeting Infrared for Night (LANTIRN) system.

MYSTIC evolved from a Hughes study on the utility and feasibility of combining imagery from several airborne sensors and data sources on a single real-time display (DDC Document AD HO 43355). The concept of simultaneous sensor display utilization is derived as follows. Increasing the number of sensors on an aircraft increases the probability of successful target acquisition because of the target's multi-spectral attributes. This is especially true when countermeasures are employed since the target cannot easily deny all its spectral signatures simultaneously. However, increasing the number of independent sensors increases pilot workload and eventually detracts from his capabilities. Missions such as low-level penetrations and weapons delivery at night intensify the problem. Multiple sensor displays require that the observer spend much of his time searching the displays. Time-shared displays require visual reorientation for each sensor change and also continued switching to determine the best display. Combining sensor imagery by simple additive mixing has been shown to degrade the total content. Hence the ideal system is one which can extract required information from the individual sensor imageries and combine the information to form a useful and easily interpreted presentation for the pilot. The MYSTIC program seeks to develop and implement simultaneous sensor concepts to produce an enhanced autonomous target acquisition capability for attack aircraft. Candidate sensors include multi-mode radar, FLIR, a laser system, radar warning receiver, electronic countermeasures (ECM), navigation data (inertial navigation system (INS), GPS), and a prior and/or linked data (i.e., target threat data base and joint tactical information display system (JTIDS)). Advanced processors would align sensor information, extract and classify target signatures, develop display presentations, and facilitate alignment

and handoff with E-O, radar, and unguided weapons. Multisensor confirmation of targets is expected to:

1) Increase the probability of detecting between targets;
2) Increase the probability of discriminating between targets and decoys;
3) Reduce false alarms;
4) Reduce susceptibility to countermeasures.

Automatic target detection and classification are key elements of Hughes' multi-sensor development. Scan conversion techniques and image enhancement are also important elements. Processing techniques are also under development to align and correlate the individual sensor sources.

Following their MYSTIC presentation Hughes personnel discussed the LANTIRN program. The basic premise behind this weapon delivery and navigation program is to defeat the Russian Armor threat in the European scenario. It is well known that the Eastern Block has numerical superiority in armored vehicles and unless the Western Block increases its tank destroying capability it might be overwhelmed in a short period of time.

In order to reverse this trend it is claimed that air power must "kill" 2000-3000 tanks per day for roughly 10 days.

The aircraft selected for this program are the A-10 and F-16, modified to take the LANTIRN pod, as well as a wide field-of-view head-up display (HUD). It is intended that these modifications should make the aircraft autonomous.

The LANTIRN system will provide the following additional operational facilities:

1) Provide wide-angle IR sensor for navigation at night and under adverse weather.

2) Provide separate narrow-angle IR sensor for target acquisition, classification, and IR missile handoff.

3) Provide video for HUD and heads-down display (HDD).

4) Provide automatic system for weapon delivery as six IR Mavericks may have to be launched in 12 seconds.

5) Provide laser ranger and designator.

6) By using on-board real-time DMA digital data, provide manual and automatic TF/TA system.

7) Improve covert environment of aircraft by increasing reliance on digital terrain data and reducing radar emission.

Copies of the viewgraphs shown by Hughes in their E-O presentations are contained in Appendix B.

An elaborate and detailed presentation on Radar Advanced Development was given by the Radar and Digital System Division of TI. TI first discussed future tactical air-to- ground scenarios, pointing out the current serious deficiency in capabilities to effectively perform night/all-weather air-to-surface attack missions. The solution: an advanced tactical fighter with autonomous capability to detect, attack, and destroy targets during night and all weather conditions. In relation to requirements for advanced air-to-ground radar systems in such an aircraft, TI discussed

Table 3.1.3-1 KEY AIR-TO-GROUND RADAR CHARACTERISTICS

Modes/Function	Capability	Comments
DBS	15 m range resolution 10:1, 20:1 beamsplitting	Target area location cue for high resolution modes
GMTI/GMTT	15 m range resolution 10:1, 20:1 beamsplitting	Simultaneous DBS for contextual location, array recognition
Spot light map	15 by 15 m resolution	Precision NAV, large target detection
	3 by 3 m resolution	Small target detection, slow moving target detection
Air to Air	Low/medium/high PRF 30 m range resolution 10:1 beamsplitting sparrow compatible	Coherent sidelobes discriminant dual mode transmitter beamsplitting for raid assessment
Covert, target identification	100-500 MHz bandwidth Programmable power	

*Taken from TI presentation materials

applicable missions including close air support, interdiction, and deep strike as well as the related mission segments including precision navigation, target acquisition, survivability, emitter location and destruction, self-defense, and maritime strike. Low levels and high speeds were cited as the primary mission profiles. TI stated that suitable radar equipment is not available today and will require major developmental activity. Table 3.1.3-1 lists the key air-to-ground radar characteristics required. TI went on to discuss specific radar operational requirements necessary in the previously cited mission segments. The radar modes required for precision navigation include real-beam mapping, Doppler beam sharpening (DBS), spotlight image (using SAR), and velocity measurement. Key radar elements required to facilitate precision target location include antenna position in inertial coordinates, radar velocity measurements, high resolution SAR target detection, and track and DMA terrain data storage and correlation. In association with radar targeting capabilities, requirements include moving target indication (MTI)/moving target track (MTT), ground MTI (GMTI)/ground MTT (GMTT)/DBS map, spotlight image, air-to-ground ranging, ground target track, and target classification. To enhance survivability, automatic terrain following, covert/stealth operation, and effective electronic counter-countermeasures (ECCM) are deemed necessary. Defense Suppression requirements include passive search, passive acquisition and track, range estimation, active acquisition, and active tracking. Long range detection along with target classification are necessary for maritime strike operations. Feasible techniques for radar target classification were discussed. Comparing anticipated radar requirements to the existing technology, TI noted a necessity for development in the following areas:

1) Acquisition of high-resolution data bases

2) Target classification, identification, and prioritization

3) Multi-sensor data correlation

4) Automation for increased efficiency of data extraction

It was noted that current radar systems lack the capacity to fully use the sensor data. Signal processing capacity deficiencies were claimed to be primarily due to limitations of throughput, memory, and versatility. TI believes these limitations can be overcome through optimization of architectural structures, component development, and the development of algorithms to define signal processor requirements and optimize the efficiency of sensor data extraction. In the context of planned developmental activities, TI also discussed two of their existing programs: the Radar Target Classification System (RAMTAC) and the Airborne Electronic Terrain Map System (AETMS). TI concluded with a set of radar system projections for the 1990's, shown in Table 3.1.3-2. A great deal of information was conveyed in this presentation. For some of the finer details, refer to Appendix C which contains copies of the viewgraphs used in the TI presentation.

An informal meeting was held with personnel from the Radar System Group of Hughes Aircraft Company. The evolution of the discussions was very similar to the context and ideology of the TI presentation. Two relevant predictions added by Hughes were achievable SAR resolution of 7 ft and MTI detection down to 1-2 ft per sec. See Appendix B for Hughes Aircraft Company presentation material.

3.1.4 User Contacts.

Early in the study FDL organized a series of briefings to present various Air Force views on the projected state of the art in sensor systems. As most of the presentations were secret, no detailed data will be described.

Table 3.1.3-2 PROJECTIONS FOR THE 1990'S

- o Advanced technology development (very high speed integrated circuits (VHSIC) and phased arrays) will significantly enhance operational capability

- o Multiple primary radar modes will operate on an interlaced time-line basis

- o Operation of primary radar resources will be automated (particularly low-level harmonization) - operator will cancel/continue/reinstate system operation

- o Target identification/classification/priorization will be:

  - Automated
  - Optimized for mission

- o Primary radar resources will play a larger role (e.g., SPW) role in delivery of low-cost weapons

- o Stored data bases (DMA, radiometric, etc.), power management (adaptive) and versatile waveform generation (coded) will enhance covertness

- o Integrated display system will provide a standardized interface to all sensors (image processing functions); fusion of data from multiple sensors (i.e., radar, IR) will increase probability of target recognition

- o Forecast reduction of resources (based on constant 1980 performance level)

  - Size 0.25
  - Power 0.10
  - Weight 0.25

*Taken from TI presentation materials

The first presentation was given by Captain Mike Poore of the Air Force Avionics Lab (AL), Reconnaissance and Weapon Delivery Division.

His presentation emphasized a need for higher resolution and real time operation. In particular, he pointed out that reconnaissance could not afford the delays of returning data to a base for processing prior to dissemination. In fact, he suggested that reconnaissance and strike might have to be from common platforms.

The second presentation was given by Lieutenant James Offen AFAL/RWT and described the development of the generation of 3-dimensional computer generated images from DMAAC data as a real time airborne system.

This program is significant because of the following reasons. The DMAAC data is correlated with radar and radar altimeter height data as in Terrain Comparison and an image is generated for the pilot for comparison with the visual or sensor images or in their place if those are not available. Data can be added to the scene (e.g., a target weapon site, etc.), whether directly viewable or occluded. In addition, the DMAAC data can provide TF/TA data when not available from FLR, should automatic TF be required. The DMAAC data can also provide data for flight path generation beyond the line of sight.

The third presentation was given by Jerry Pasek of AL/RWM. Mr. Pasek's presentation was dedicated entirely to Electronically Agile Radar (EAR) and SAR. Of particular significance in this presentation was the high quality of the radar generated images.

The fourth presentation was given by Squadron Leader Stewart Brussell (RAF, attached to AL). Mr. Brussell discussed Integrated Strike Avionics Study, and Display for Correlated Sensor Data. Basically, the first program will correlate, screen, and perhaps

simplify the inputs from a number of sensor systems while the second program will define a display system to adequately present this data to the crew members. This type of program is under investigation using digital video techniques by organizations such as Hughes and Westinghouse.

Figure 3.1.4-1 shows the variety of inputs that have to be considered.

The final presentation was given by Gil Kuperman of AMRL H/HEA and it concentrated on the particular problems of sensor systems and operational requirements.

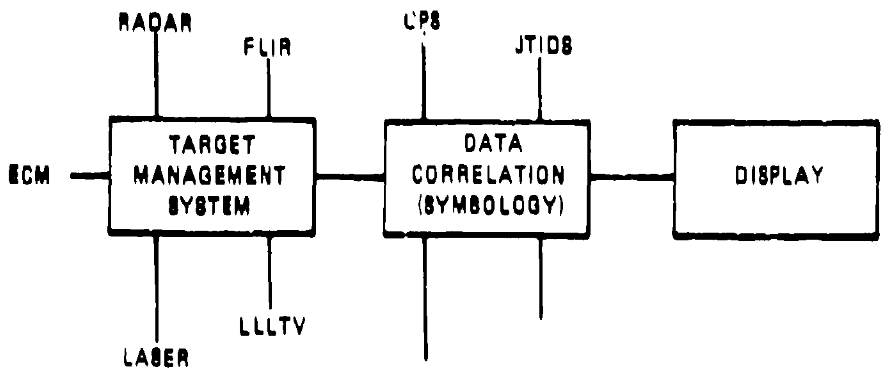

Figure 3.1.4-1 MULTISENSOR DATA CORRELATION

3.2 ANALYSIS

3.2.1 Sensor Characteristics and Trends

3.2.1.1 Radar Devices

This section summarizes the results of an investigation of radar developments expected during the 1980's, particularly as they relate to simulation. An investigation of the radar capabilities anticipated during the 1980's was considered a necessary first step in comparing the simulation requirements of the future to the current capabilities of FDL. Coupled with a knowledge of the current state of the art in radar simulation, this comparison led to recommendations to FDL for upgrading their simulation capability to meet their needs during the 1980's (see Section 6.0). Figure 3.2.1.1-1 is the Frequency Designation Chart showing radar bands versus frequency. Figure 3.2.1.1-2 is an IR Transmittance versus Wavelength Chart illustrating atmospheric windows for IR.

3.2.1.1.1 Microwave Sensor Systems

Microwave detectors contain a receiving directive antenna system, arranged for sequential scanning of a field of view (FOV), and operated in conjunction with a suitable microwave receiver.

Microwave sensors are of two types: one is a passive system, composed of antenna, receiver, and display to show the microwaves emitted by objects in the FOV, in a manner similar to passive IR systems. The second type is an active radar system. Here the FOV is illuminated by locally generated microwave energy, and that portion reflected from objects within this region is amplified and displayed.

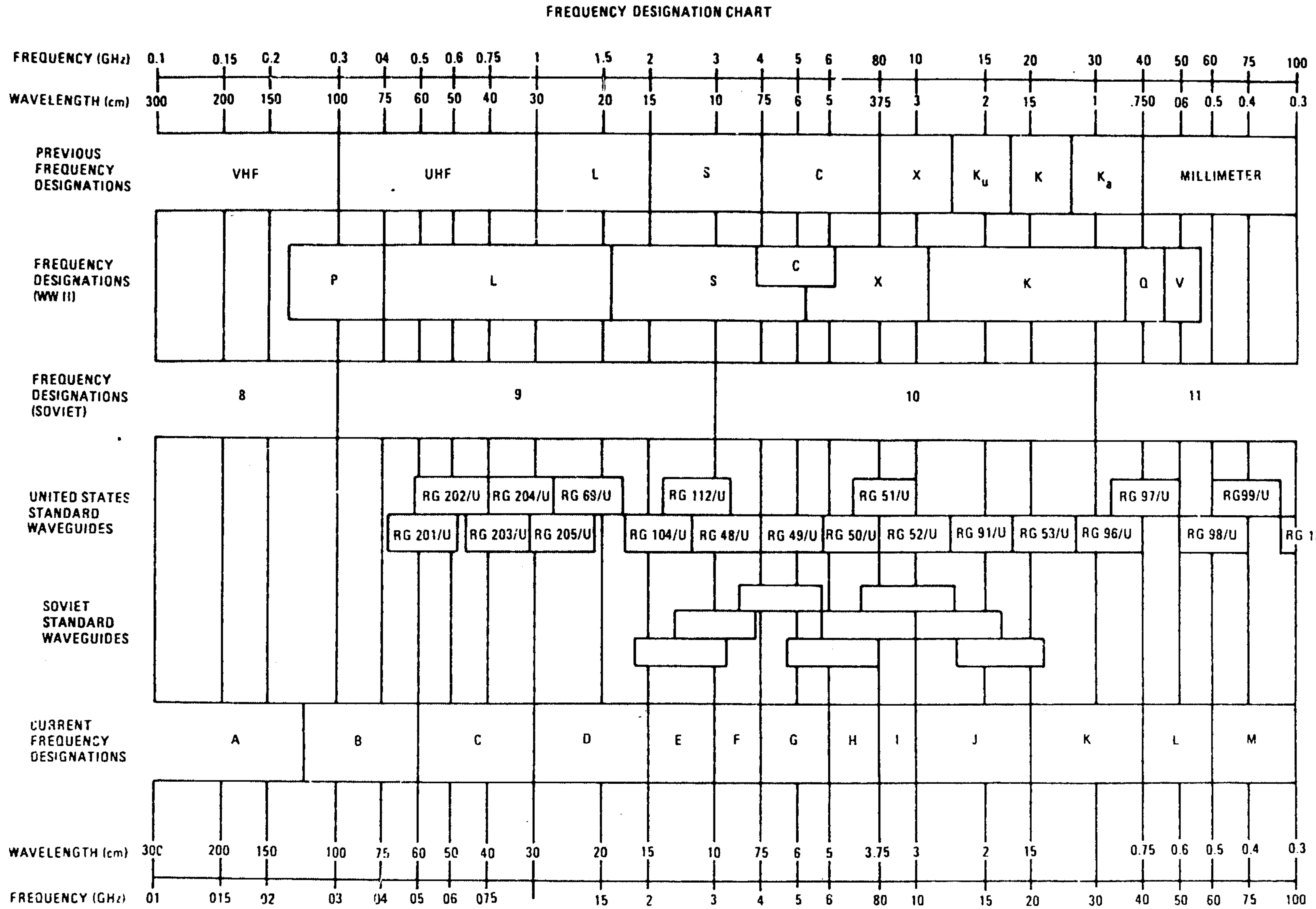

Figure 3.2.1.1-1 FREQUENCY DESIGNATION CHART

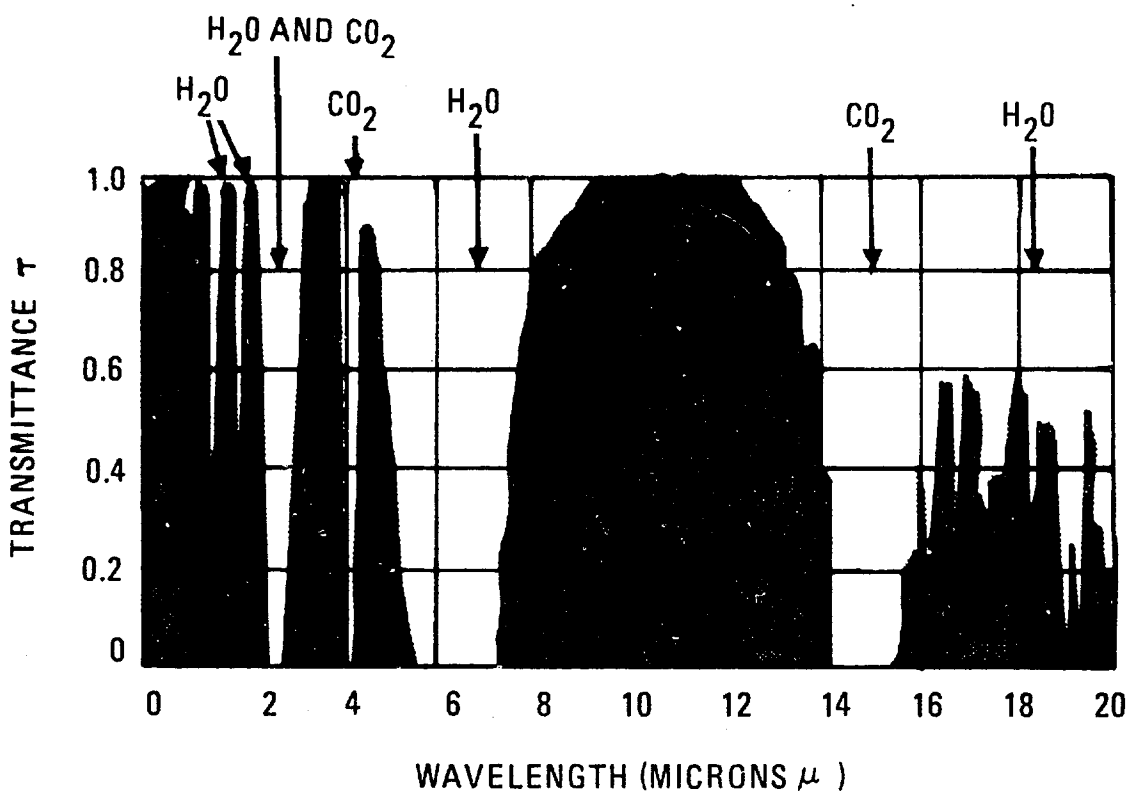

Figure 3.2.1.1-2 TRANSMITTANCE VERSUS WAVELENGTH CHART

Spectral Ranges of Interest - The spectral range of microwave radiation runs from wavelengths of about 0.1 cm (1,000 μm to 300 cm. All spectral ranges are of potential interest, but particularly heavy use is made of the following bands used for many common types of surveillance/attack radars: X-Band, 3-5 cm (frequency 5-11 GHz); and K-Band, 1-3 cm (frequency 11-30 GHz). Also, interest is strong in the M-Band, 0.3-0.5 cm (frequency 60-100 GHz) for physically small passive sensors.

Atmospheric attenuation of microwave signals occurs, but not in the form of windows as for IR but rather with smooth attenuation, decreasing as a function of increasing wavelength. Precipitation attenuation effects occur, also decreasing smoothly as a function of increasing wavelength.

Sensor Resolutions - Azimuth resolution is a function of the microwave antenna beamwidth in the horizontal direction. A typical value for one cm wavelength and 30 cm paraboloidal reflector diameter is 2° beamwidth.

Range resolution for a radar is a function of transmitted pulse length which provides pulsed illumination of the FOV. Typical transmitted pulses are of the order of μs in length. For a passive sensor, range resolution is a function of antenna beamwidth in the vertical direction.

3.2.1.1.2 General Trends

The investigation was limited to airborne radar, with particular emphasis placed on the various air-to-air and air-to-surface missions identified in the FDL facility long range plan. Observations were grouped into two general categories; those relating to general trends common to many forms of radar and those unique to a specific generic type of radar.

Again, the emphasis was on those characteristics important from a simulation standpoint. One of the first, and perhaps most significant observations, was the realization that radar is basically a mature technology. The changes taking place today are not the result of fundamental advances in radar technology, but rather advances in other technologies which are now making it feasible to implement radar techniques which have been known for some time.

Perhaps the single most important trend has been the progress made in digital technology. Techniques which were known but not previously feasible have been making their way into new radar designs as the advance in digital technology placed more and more powerful tools in the hands of the radar designers. This trend will continue through the decade. Recent technology forecasts project major advances in digital technology. Circuit packaging densities will increase by a factor of five with speeds increasing by factors of one hundred. Propagation delays will be measured in picoseconds. Rockwell International is currently designing an 8 by 8 multiplier with a multiply time of 6 nsec.

These tremendous increases in processing capability will result in an extension of trends we have already seen. More and more radars will become multi-mode devices. There will be more automation and increasing use of digital computers. Processing algorithms will become more sophisticated, resulting in better detection capability, improved signal-to-noise ratios (SNR), more ECCM capabilities, better resolution, and perhaps even target recognition and identification. More and more radar parameters which were previously fixed by the system design will become variable and under program control of the radar processor. Carrier frequency, pulse repetition frequency (PRF), waveform, and transmitter power will all become computer-controlled.

As the degree of processing increases, the display presented to the crew will become more and more synthetic. Raw video displays will be first supplemented and eventually replaced by synthetic displays. The familiar radar target blip will be replaced by a computer generated graphic symbol, perhaps in color, that will indicate target location, heading, speed, range, altitude, and other sensor-derived information. Radar data will be combined with data from other sensors and also compared against stored terrain data for correlation, navigation, improved targeting accuracies, and increased target detection capability.

Many radars will become multi-purpose. Previously designed systems were generally dedicated to a specific task. If the resulting system happened to have a secondary capability, it was usually very limited or of poor quality. Because of computer control and complex signal processing, new systems will be able to perform multiple functions and do all of them well.

3.2.1.1.3 Forward-Looking Radar

Many of these developing trends present significant challenges to the radar simulation community. The remainder of this section will deal with some specific problems presented by emerging radar technology. The first problem is that of sheer complexity. Past radars have had limited flexibility. A terrain following radar didn't do much else. An air-to-air radar had very limited ground mapping capability.

In contrast, the radars of the future will have great flexibility. For example, the F-18 APG-65 is a coherent pulse-Doppler radar built by Hughes. With the exception of the programmable gridded traveling-wave tube, it is fully digital, including a programmable signal processor which employs a 256K word disk and 161 words of working storage. The system employs both high and medium PRF, can interleave them for range-while-search mode or

three automatic-lock-on dogfight modes, and uses DBS techniques for raid assessment. A track-while-scan capability will maintain track files on ten simultaneous targets. For air-to-ground operations, the system offers standard ground mapping and air-to-ground ranging along with moving target indication and tracking, fixed target tracking, TA, sea surface search, and DBS capability with sharpening ratios of 19:1 and 65:1. As an indication of the resolution being achieved, Hughes has stated that carrier arrestor wires can be resolved on radar at 19 km out on approach, the equivalent of about 18 m definition in range and 9 m in azimuth, according to the company.

3.2.1.1.4 Synthetic Aperture Radar

Synthetic Aperture Radars (SAR) provide serious challenge to the radar simulation engineer. SAR is a concept that has been known for over 10 years. It consists of complex processing techniques applied to a collection of radar data collected over a period of time from a moving platform. Platform motion creates a synthetic aperture, or the equivalent of a much larger physical antenna, with a corresponding decrease in apparent antenna beamwidth. Proper processing can focus the beam so that changes in range that occur during the data collection from a target will not cause smearing due to the Doppler shift caused by the range change.

These systems are capable of very high resolution ground maps, with range and azimuth resolutions under 10 ft. Processing is so complex that these systems have previously been limited to non-real-time reconnaissance use. Data was stored on film, which was then developed and processed, resulting in significant time delays between the actual data collection and final results. Refinements were made until the time delays were reduced to several minutes. Modern digital technology now makes it possible to perform this very complex processing in real time. Crew members will

have a very high resolution ground map display available to them in real time, which would greatly improve target detection, navigation, and weapons delivery capabilities.

3.2.1.1.5 Terrain Following Radar

TF radar capability will find its way into more aircraft during the 1980's as survivability considerations place more and more value on high-speed low-level flight. Set clearances will probably come down to about 100 ft. TF capability will most probably be accompanied by a compatible terrain avoidance mode. This feature displays terrain which protrudes above a clearance plane, and provides cues to allow azimuth steering to maximize the cover provided by the nearby terrain.

There may be a possibility of supplementing the TF capability with some form of terrain matching system. Using a stored data base defining known terrain features, it has been demonstrated that precise low-level navigation is feasible over long distances by comparing radar returns against stored data bases. It is easy to visualize this type of system integrated with a TF/TA radar to enhance overall capability and provide a higher confidence level necessary for automatic, high speed, all weather, day/night, low-level flight.

3.2.1.1.6 Electronically Agile Radar

EAR, originally intended for use on the B-1 or B-52, has been in development at Westinghouse since 1974. This is the first attempt at developing an airborne system which employs a phased array antenna (not to be confused with a planar array). The feature that makes the phased array unique is that the radiated beam is controlled electronically, rather than mechanically. The system being developed by Westinghouse uses over 1800 independent phase shifters/radiators. By controlling the relative phase being

applied to the individual elements, the resulting beam can be formed electronically.

This provides two important characteristics. First, the radiated beam can be randomly positioned on a pulse-by-pulse basis anywhere within the total antenna coverage. Secondly, the beam shape may also be altered on a pulse by pulse basis. This leads to many possibilities, such as tracking multiple targets by hopping the beam from target to target, tracking targets in several locations while searching in a different area, and even going so far as to time-share major modes. For example, a fan beam scanning a TF scan pattern could be interleaved with a conventional spoiled beam ground-mapping search pattern while a pencil beam maintained track on an airborne target. This special beam shape, called a cosecant squared beam, is required for airborne radars that scan a large ground area for radar navigation (ground mapping). It is narrow in the horizontal plane but broad in the vertical plane. For optimum radar ground mapping, the particular section on the ground that is being scanned must not be uniformly illuminated by the radar beam. Instead, the ground and objects on the ground under the aircraft should be illuminated by a small amount of power, while more distant objects in the scan sector are illuminated by a greater amount of power. Therefore, the intensity of the beam varies as the cosecant of the angle between the horizontal and a line drawn between the aircraft and a given point on the ground. This results in an approximately equal amount of energy reflection throughout the scan sector. A common method used to obtain this type beam is to use a special reflector on top of the parabloic dish. This reflector spoils the vertical plane of the normal pencil beam. Because of this, the beam is also referred to as a spoiled beam. The possibilities with such a beam are numerous.

3.2.1.1.7 Radar Displays

Radar displays for military airborne radars have traditionally been dedicated cathode ray tube (CRT) displays from 4-8 in. Both conventional CRT's as well as storage tubes are used, with a variety of phosphors. Many of the conventional CRT's are special high brightness tubes and nearly all displays use external filters to accommodate the very wide range of ambient light encountered in an aircraft cockpit. Deflection circuits may be either electrostatic or electromagnetic. Some older designs (F-111, B-1) employed a servo-driven yoke for deflection and an optically ported CRT (to allow strike photos to be taken from the face of the CRT.)

Traditional radar displays are presented in a variety of formats, with the most common including B-scan and single-radius offset plan position indicator (PPI). The B-scan display is a range-azimuth display in which a target return is displayed as a brightening of the sweep. Horizontal displacement of the scan from the center of the scope corresponds to the angular position in azimuth of the antenna. Range is represented by the vertical distance from the trace origin at the bottom of the scope. The B-scan is therefore a distorted horizontal projection of the sector being searched; the distortion a result of the fact that azimuth angle is represented as a rectangular coordinate instead of converging toward the antenna as the beam actually does. The advantage of this distortion is that close-in targets are presented on an expanded azimuth scale and the azimuth of these targets can be more easily read. However, this distortion must be remembered when using the B-scan for mapping or navigation purposes.

The PPI scan, a modified B-scan in which rectangular coordinates are replaced by polar coordinates, displays range and bearing information. The trace is generated by sweeping the intensity spot outward from the center of the scope each time a pulse is

transmitted. Targets are displayed by a brightening of the sweep as in the B-scan. As the antenna rotates the trace rotates around the center of the indicator so that the angle of the radial line on which the target appears indicates the azimuth of the antenna beam. The distance from the center of the indicator indicates range. This type of scan makes it possible to produce a map of the territory surrounding the observing station of the indicator. This display is especially useful for wide-area searching, navigation, and mapping.

For ground mapping, displays up to ±60° by 200 mi range are typical while weapon delivery might use a display of ±5° by 2.5 mi. Newer Doppler systems often use a B-scan format to display range rate versus azimuth angle.

The growing number of aircraft sensors and the increasing amount of data available for display (in a very limited space) has led to the concept of multiple purpose displays based on time sharing one display head for various sensors or computer generated displays. The same CRT may be used to display E-W, radar data, FLIR, weapon TV, electronic automatic direction indicator (ADI), or LLLTV during various phases of a mission. Each of these displays will most likely contain additional symbology superimposed on the basic display. This concept has led to the development of raster scan display formats driven from a scan converter.

As the trend in scan converters has shifted from analog to digital, the trend in radar displays has also shifted from analog (raw video) to digitized video a discrete number of fixed grey scales. This trend has resulted from the advent of digital scan converters and also from the large increase in digital signal processing associated with modern radars. Scan conversion is required to present information from various sensors in various formats on a common display in a common format. It also provides a means to superimpose computer controlled symbology or computer generated

displays with sensor inputs. Digital signal processing is being used to improve target detection and recognition, improve SNR's, reduce clutter and false alarms, and aid the operator in display interpretation. In some highly processed radar systems, the operator never actually views sensor video. He is presented with a display that consists entirely of symbology, including target returns.

The next logical extension in displays would be to increase the use of color to aid in rapid operator interpretation of the tactical situation being displayed. Another technique being investigated is the combination of information from several sensors on a single display. An IR or TV display might be superimposed on a radar return to produce a composite display that contains more information than either of the component parts.

Obviously, other forms of displays are being investigated as replacements for the CRT. Flat panel plasma displays and light emitting diode (LED) matrix arrays are being considered as alternates, but the CRT seems destined to remain as the dominant display technology for the near future.

3.2.1.1.8 Radar Simulation Problems

There are several other unique types of radar appearing in the literature, including bistatic, millimeter wavelength, and foliage penetration radars. However, the types previously described appear to offer the highest probability of being encountered, and they offer some unique challenges to the radar simulation community. First, and perhaps most significant, is the problem of resolution. Past radar simulations have employed either film plates or DDB's for both reflectivity and terrain elevation data. Neither of the existing approaches can provide acceptable solutions for the systems of the 1980's. Film-based systems offer large areas of coverage, but their resolution is

limited to about 250 ft, using existing maps and scale factors. Digital systems in use also have nominal resolutions in the 250-ft range, with selected areas (of limited size) perhaps stored to 100-ft resolution. Neither of these approaches the 10-ft or better resolution needed for the systems of the 1980's.

The problem is also complicated by the fact that source data is simply not available with 10-ft resolution. DMA is preparing global data at Level I with 500-ft resolution, and limited areas of Level II data to 100-ft resolution. Level I data is scheduled for completion between 1985 and 1990 time frame. Level II data, which costs 10 to 100 times as much to produce, will be limited to selected areas only. Data with 10-ft resolution must simply be assumed unavailable in the time frame of this study.

Currently, the DMA data base contains only gross descriptions of many features. For example, urban areas can be identified as "60% buildings" and other areas simply as "forest". Link has investigated synthetic breakup techniques which are pseudorandom methods of generating realistic radar returns for these areas. Various forms of texture have been evaluated. Good feature breakup can currently be provided with texture as long as correlation is maintained from sweep to sweep. At this time it does not appear necessary to maintain the same kind of correlation scan to scan since these areas, when presented on the actual radar, do not necessarily maintain correlation from scan to scan. Investigation is continuing.

Texture is added by modifying the radar return across features representing forests, urban areas, etc. Several different methods of accomplishing this have been developed. The texture patterns for each of these areas will be selected from stored signatures (or computer algorithms) by the surface feature code. Spatial frequency of the breakup is varied to represent different surface character but contrast and area affected by breakup are limited to avoid the appearance of artifically created features.

Assuming the resolution problem is overcome, the next area of concern is correlation. As more and more detail is added to the radar presentation, there are more and more features to be noted by an observer. A visual scene and a radar presentation generated with 500-ft resolution might appear very well correlated. However, the same scenes generated with 10-ft resolution might appear poorly correlated. Correlation can present problems in scene content as well as relative position. Objects detected on one sensor must be detectable on all other appropriate sensors (as well as visual), and must maintain positional accuracy on all displays. As resolution continues to improve, it will become more vital to use a common data base for all sensors and visual displays.

Electronically agile radar presents an additional problem to be solved. Current digital landmass simulations all take advantage of the continuous nature of conventional antenna scan patterns to minimize the amount of high speed storage needed for display generation. Data immediately ahead of the antenna is the only data which normally resides in high speed memory. With the random scan position used by EAR, new techniques will have to be developed for data management, or costly increases in high speed memory will be required.

These are but a few of the problems to be solved to allow simulation of the radars being developed for use in the 1980's.

Advances in digital technology, radar signal processing, and microwave techniques will bring continuing advances in the capabilities of future radar systems. Simulation techniques, system designs, and general performance requirements will continue to challenge the inventiveness of the simulation community during the 80's.

3.2.1.2 Electro-Optical Sensors

Various E-O sensors that should be considered for existing or near future systems are:

1) TV - Daytime medium resolution TV, high resolution TV, LLLTV, missile TV

2) IR - FLIR, missile imaging IR (MIIR), IR search and track (IRST), IR nose and tail warning

3) Laser - Laser spot tracker (LST), laser warning receiver (LWR), laser ranger and designator.

Rather than deploying new types of sensors in the near future, the trend is toward improving the sensors already available. Emphasis will most likely be in common displays, enhanced images, and more automatic and decision making features. These advanced sensors would be less of a problem in a simulated system than in the actual aircraft system since many of the real-world complex functions, such as automatic target screening and classification, could be defined in advance in the simulated environment. Image generating and display equipment in the simulator should be capable of providing higher resolutions than are required for present sensors so that any improvements in real world equipment would be of minor consequence.

3.2.1.2.1 Television

TV sensors provide video imagery of contrasting luminance in an azimuth-elevation format. The imagery can be used for a variety of tasks, such as terrain and target observation, and as an aid for flight control and weapons delivery. TV sensors become less effective as the scene illumination decreases, and are also adversely affected by fog, clouds and smoke. Various TV systems

contain different operating characteristics, such as resolution, field of view, scan lines, etc. Typical characteristics are listed in Table 3.2.1.2.1-1. The TV display can be useful for medium-to-close range observations with minimum interpretation since the video scene is a close representation of the actual scene. TV sensors, like most E-O sensors, are gimballed and their particular field of view can be slewed within a particular field of coverage. This feature can also be utilized for target tracking and slaving to other sensors. For low light levels or night-time operation, LLLTV with image intensifiers are used. The image resolution is proportional to the scene illumination and will become noisy with a poor contrast and a granular display appearance as the scene falls below approximately 1/4 moonlight illumination. Future LLLTV systems may use lasers to scan the scene and improve the natural illumination but the final displayed scene probably would not change very much and therefore would have little effect on a simulated system. Missile TV usually provides a lower resolution image compared to daytime TV and the aspect ratio could be 1:1 rather than 4:3. The effective operational range for most TV systems is generally less than 10 mi. Video bandwidths for the various TV systems range from 5-25 MHz.

3.2.1.2.2 Infrared

IR sensors are very important for night-time operations and for detecting strong IR emitters such as aircraft, missiles, vehicles, factories, etc. IR applications are similar to TV but are not limited by scene illumination. TV is severely affected by clouds and smoke compared to IR sensors; however, water vapor does limit IR performance and humid fog will have a severe attenuating effect. There are various types of IR systems and typical general characteristics are listed in Table 3.2.1.2.2-1. FLIR and imaging IR's present a video image of the outside scene similar to TV; however, temperature differences are sensed and displayed rather than luminance differences. FLIR resolutions are often lower than

Table 3.2.1.2.1-1 TYPICAL TV SENSOR CHARACTERISTICS

SENSOR	DISPLAY FORMAT	FIELD OF VIEW	FIELD OF COVERAGE	RESOLUTION	UPDATE RATE
LANTIRN	1025 lines 30 frames per sec 1:1 aspect ratio	30°	±45° azimuth +15° to -45° elevation	800 lines	1/30 sec
LLLTV	525, 875, 1024 lines 30 frames per sec 4:3 aspect ratio	Wide - 20° by 15° Medium 6.6° by 5° Narrow - 1° by 0.75°	±45° azimuth +5° to -45° elevation	300-800 lines 100-200 lines @<1/4 moonlight	1/30 sec
DAY TV	(Same as LLLTV)	(Same as LLLTV)	± 45° azimuth 0 to -135° elevation	300-800 lines	1/30 sec
HI RES TV	(Same as LLLTV)	Medium - 2° by 1.5° Narrow - 0.66° by 0.5°	± 15° azimuth ±15° elevation	300-800 lines	1/30 sec
MISSILE TV	525 lines 30 frames per sec 1:1 aspect ratio	5° by 5°	±45° azimuth +15° to -45° elevation	300 lines	1/30 sec

Table 3.2.1.2.2-1 TYPICAL IR SENSOR CHARACTERISTICS

SENSOR	DISPLAY FORMAT	FIELD OF VIEW	FIELD OF COVERAGE	RESOLUTION	UPDATE RATE
FLIR	525, 875 lines 30 frames per sec 4:3, 1:1 aspect ratio	Wide - 16° by 12° Medium - 4° by 3° Narrow - 2° by 1.5°	±45° azimuth ±5° to -35° elevation	< 1 mrad	1/30 sec
MISSILE FLIR	525 lines 30 frames per sec 1:1 aspect ratio	Medium - 3° by 3° Narrow - 1.5° by 1.5°	±45° azimuth +15° to -45° elevation	< 1 mrad	1/30 sec
IRST	525, 875 lines 30 frames per sec (scan converter) 1:1 aspect ratio	0.1° by 0.1°	±60° azimuth ±90° elevation	< 1 mrad	4 sec
IR NOSE AND TAIL WARNING	Symbology E - O	0.5° by 2.5°	±90° azimuth ±30° elevation	1 mrad	3 sec

daytime TV. Occasionally FLIR sensor update rates are on the order of 15-20 frames per sec but are usually converted to 30 frames per sec for a standard cockpit display. FLIR sensors are also gimballed and can be slewed in much the same manner as TV sensors. Although FLIR's are ideally suited for hot spot detection and target acquisition, applications such as ground mapping require some interpretation since the thermal characteristics of most objects vary at different times of the day or night and with climatic conditions. The effective operational range for most imaging IR systems is generally less than 10 mi. MIIR is similar to FLIR but generally has lower effective resolution and can have a 1:1 aspect ratio. IRST search and track and nose and tail warning sensors usually consist of a smaller number of detectors which are rapidly scanned through a larger field of coverage and with longer range capabilities. Typical ranges for IRST, which can be positioned for nose or tail warning, are 15 mi for nose and 80 mi for tail sensors. Other IR warning systems have 5-mi nose and 25-mi tail ranges. These sensors are intended to detect and possibly track anti-craft missiles and interceptors. IR nose and tail warnings are usually displayed as symbols and may also generate an aural cue or illuminate a lamp indicator. Update rates for some of these sensors can be up to 5 sec but they are usually processed by means of a scan converter to provide a standard 30-frame display rate when presented on a CRT display.

3.2.1.2.2.1 Infrared Sensor Systems

The spectral range of infrared radiation runs in wavelengths from about 0.75 μm to 1,000 μm with regions of particular interest from about 1.0 μm to 30 μm For infrared sensor atmosphere, a number of atmospheric windows exist with infrared transmission efficiencies of up to 90% in these regions. The bands within atmospheric windows which are of interest to ground-vehicle and low-level airborne IR sensors are approximately 0.3-1.5 μm (visible to near IR), 3.0-5.5 μm, and 8.0-14.0 μm.

IR detectors are of two major types: thermal detectors and quantum detectors. Thermal detectors operate by absorption of infrared radiation within a bulk detector material. This may cause a temperature change in gas pressure, as in a Golay cell, or change electrical polarization of a crystal, as in pyroelectric detectors. Thermal detectors are of relatively low sensitivity but are independent of the wavelength of the incident radiation and often may be operated at room temperature. Quantum detectors operate through interaction of incident photons with electrons in a solid, operating as a semiconductor. Quantum detectors are a function of the incident radiation wavelength, and usually must be operated at reduced temperatures.

These detectors are used in two major types of IR sensors: devices which use mechanical scanning of the field of view, and devices which use electronic scanning. A typical example of a sensor using mechanical scanning is the Bendix Thermal Mapper. This device provides a resolution of 2.5 mrad, field-of-view scan angle of 120°, and temperature sensitivity of 0.5° C. The detector is an indium antimonide unit, cooled with liquid nitrogen, which covers a wavelength band of 0.7-5.5 μm.

Other similar devices typically use mercury cadmium telluride detectors, cooled with liquid helium, covering a wavelength band of 8-14 μm. An example of a sensor which uses electronic scanning is a pyrolitic vidicon detector, which is a vidicon camera tube with pyroelectric target material. This tube is scanned in a manner similar to TV, except that the input infrared radiation must be chopped, and the output waveforms reshaped, since the pyroelectric effect responds only to changes in the radiation levels. Work is in progress on solid state charge-coupled devices which do not need the vidicon tube with electronic scanning, but use arrays of quantum detectors, together with associated state-integrating circuitry.

3.2.1.2.2.2 Sensor Resolutions

A definition of resolution for a camera IR sensor is the number of resolvable picture elements in the field-of-view. A typical pyrolitic vidicon camera as described in Section 3.2.1.2.2.1 has a standard 525-line TV format, so the number of picture elements is 525 by 700 or 367,500. Special cameras, such as the RCA QTV-8 return-beam vidicon have a field-of-view resolution of 5,000 TV lines, in a square format, for a total of 25 by 10^6 picture elements. Currently this tube provides response in the visible and near-IR region only.

A definition of resolution for an electromechanical scanner type of IR sensor is the scan angle resolution in mrad, typically 1-2.5 mrad for present systems. This will normally provide 500-1,000 scan lines if a TV type display is used.

3.2.1.2.2.3 Sensor Slew and Zoom Rates

Various E-O sensors have different slew rates. The B-52 steerable television (STV) and FLIR sensors have slew rates of $\pm 90°$ per sec while the Pave Track pod can have a slew rate of 150° per sec. Missile sensors can have hand-controlled slew rates which can be in the order of 6° per sec.

Zoom rates are usually relatively instantaneous. The operator switches from one fixed field of view to another fixed field of view.

3.2.1.2.3 Laser

Lasers are an important means of designating targets. The LST and ranger is primarily used to track ground targets and to provide guidance and range information for weapons delivery. Symbols are generated on the sensor display that is being

utilized, which is usually FLIR or TV. The operational range is generally greater than 10 mi. Symbols are also generated by the LWR which is used to detect any threat lasers that are being directed toward the aircraft. These signals are sometimes displayed on the 360° PPI display and the range is generally limited to about 10 mi. Typical characteristics are listed in Table 3.2.1.2.3-1. Future sensor systems may utilize a combination of laser transmitters and infrared receivers which could result in a high resolution display containing range information. Lasers operate at a range of wavelengths which are between IR and TV and are therefore relatively susceptible to the same atmospheric effects.

3.2.1.2.4 Laser Radar

According to an article in a recent aviation technology publication (see Stein), laser radar has the capability of presenting a small area of coverage with high resolution as compared to conventional radar of low resolution with large area of coverage. Millimeter (mm) wave and laser radar are expected to evolve as complementary, rather than competing, technologies. Laser radar is known to have extremely accurate range-finding characteristics, as well as precise identification capabilities, while mm-wave is more efficient at penetrating battlefield and adverse weather conditions. Carbon dioxide laser radar developments at United Technologies Research Center (UTC), directed toward advanced development of two new helicopter-borne pods for the U.S. Army, promise to "usher in a true multifunction optical radar capability."

The flying laboratory had utilized a 500-lb laser obstacle and terrain avoidance warning system (LOTAWS), developed by UTC and flown successfully in 1975-76 on a Sikorsky CH-53 helicopter.

Table 3.2.1.2.3-1 TYPICAL LASER SENSOR CHARACTERISTICS

SENSOR	DISPLAY FORMAT	FIELD OF VIEW	FIELD OF COVERAGE	UPDATE RATE
LST	Symbology - E - O display, HUD gunsight	5° by 5°	$\pm$45° azimuth +15° to -45° elevation or colocated with TV or FLIR	1 sec
LWR	Symbology - Lethal range rings, PPI 360° display	360° azimuth 17C° elevation	360° azimuth 170° elevation	1 msec

The new pods will focus on NOE-oriented missions, providing TF/TA avoidance, Doppler navigation and hover, and precision search and weapon delivery capabilities.

The new pods will build on the technology developed for the LOTAWS multifunction carbon dioxide heterodyning laser radar, built and flown for the Army Avionics Research & Development Activity at Ft. Monmouth, N.J. The pods are expected to fly on an Army/Sikorsky UH-60A Black Hawk.

Pod Number 1 is planned for delivery around June, 1981. This pod's design will attempt to reduce the size and weight of present technology and provide identification processing of tank targets (see Figure 3.2.1.2.4-1). Planned dimensions of the pod are 40 in. long and 8 in. in diameter, with a weight of 125 lb.

Pod Number 2 is expected to function as a sensor for signal processing, using algorithms being developed. Future developments in target identification and weapons delivery capability are expected to use a 10-W variable output format and a programmable waveguide carbon dioxide laser transmitter. A carbon dioxide laser operates at frequencies of 10^{13} Hz, compared to about 10^{10} for an X-band radar system.

This increase of three orders of magnitude in frequency provides much smaller beam divergence, which varies inversely with frequency. Doppler sensitivity is also improved by a factor of 100 to 1,000 times.

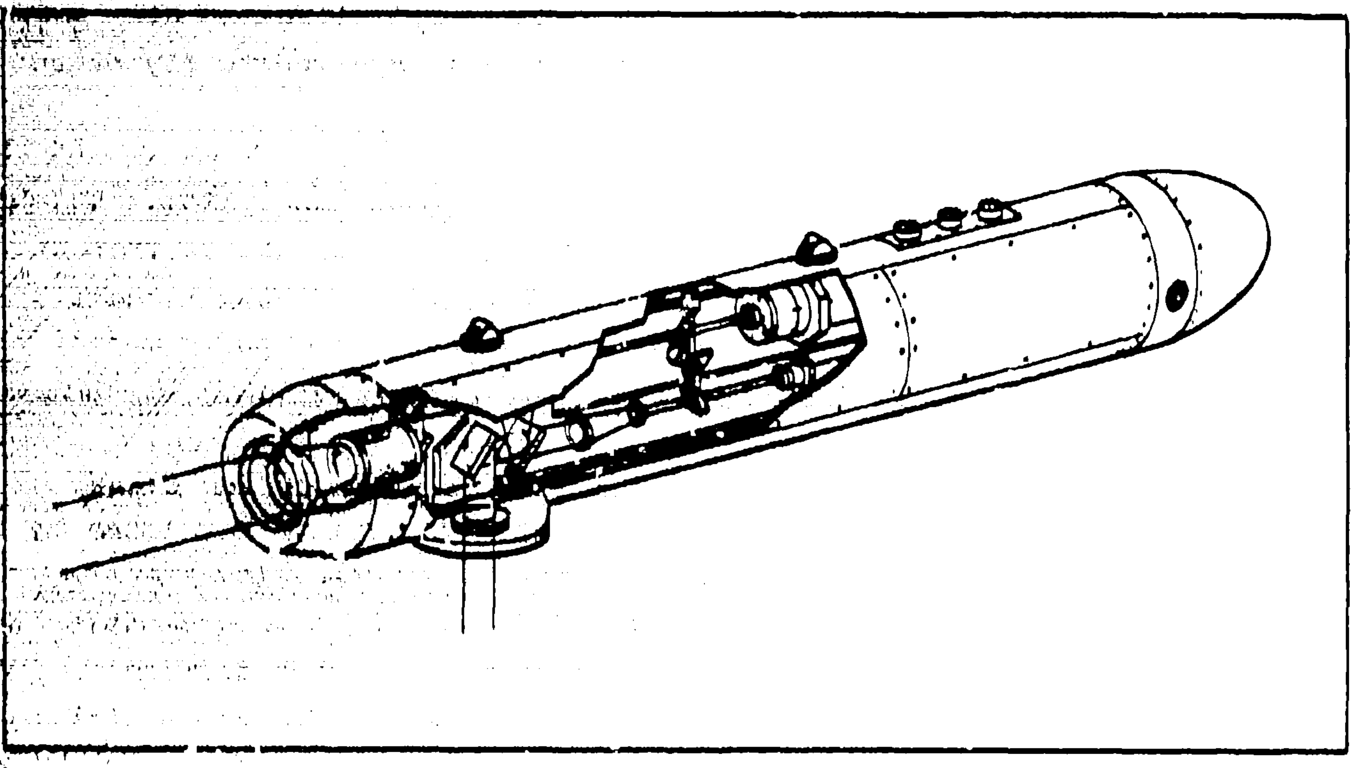

Figure 3.2.1.2.4-1 HELICOPTER-BORNE CARBON DIOXIDE LASER RADAR POD

3.2.1.2.5 Displays

Since alphanumeric messages and symbology will be provided along with sensor data on many current and future aircraft, the tendency is to use a single multifunction display. Now and in the near future CRT displays should be in use. The widespread application of other types of displays, such as liquid crystal or plasma, does not seem probable in the near future. General characteristics of a typical simulator multifunction display are as follows:

1) Viewing Area - 8.5 in. horizontal by 6.5 in. vertical
2) Phosphor - P-43
3) Video Bandwidth - 20 MHz
4) Brightness/Contrast - 8:1 contrast ratio at 500 ft-candle ambient
5) Horizontal Scan Rate - 26.25 KHz
6) Raster Lines Per Frame - 875
7) Vertical Scan Rate - 60 Hz per field, 30 Hz per frame
8) Video Input - Composite RS170 compatible or non-composite
9) Synchronization - Internal or external RS170 compatible.

4.0 MISSION TYPES AND REQUIREMENTS

The unique role of FDL's flight simulation requirement tends to impose a more severe requirement on their simulation devices than those placed on virtually all other facilities in Air Force inventory. This is due to the nature of experimentation and further, to the regime of flight and tactics required of FDL.

As stated in the statement of work (SOW), "This [the FDL] facility exists as a research and development tool for performing real-time, man-in-the-loop simulations of aircraft, flight control, and weapons delivery concepts of an advanced nature." To further compound the sophistication of the facility requirements, modern capabilities of advanced sensors and their displays are added. Just as the training simulator designer evaluates trade-offs that will provide the appropriate cue environment for the training tasks assigned in a cost-effective manner, the purpose of this study is to examine the real needs of this facility based on mission requirements and determine how to economically satisfy those needs.

In order to focus on these requirements the study team reviewed the mission needs as stated in the SOW and attempted to evaluate how best to provide those requirements. The implications of those findings should be explored before examining the specific mission. As mentioned above, the role of this facility is quite sophisticated and, in most cases, requires simulation capabilities beyond the state of the art (SOTA). The problem then becomes how to apply current and near-future SOTA to provide a creditable research capability. The answer lies in taking advantage of:

1) Experiments that (in general) will concentrate on specific short-term segments of the general mission of U.S. Air Force combat crews and,

2) The fact that this facility will not be used for training. This allows dedication of current and recommended future capabilities to specific experiment types for which they are best suited. This will be possible because unlike most training environments experiments conducted in this facility can tolerate discontinuation caused by multiplexing sensor data base sources.

4.1 SENSOR CAPABILITIES

FDL is required "to effectively conduct advanced aircraft tradeoff studies and flight control system developments under TOTAL MISSION simulation," (5-Year Plan, p.1). This man-in-the-loop engineering simulation must represent both the natural environment (terrain, foliage, and weather) and battle-induced environment (smoke, gunfire, threats, and countermeasures). Among the new cockpit elements to be involved in these tests are digital flight controls, time-shared displays, and keyboards.

The purpose of this study is to identify those simulation elements involving advanced sensors, such as TV, LLLTV, FLIR, SAR, FLR, EAR, E-O scanner tracker, and laser radar. These sensors may be operational on combat aircraft throughout the 1980's and early 1990's, and hence need to be simulated at FDL.

Unlike the past, when each sensor had its own dedicated CRT, current practice integrates a number of sensor outputs on a single CRT. This practice is dictated by limitations in cockpit space and the need to keep aircrew workload within reasonable bounds; it is easier to obtain information from a single integrated display than from several independent displays, each of which provides only one type of information. This trend to multifunction

displays produces a number of benefits in addition to conserving cockpit space and reducing aircrew workload:

1) Sensors can be modified and new sensors added without making significant cockpit modifications.

2) Reliability is increased in two ways. With a smaller number of display heads, there is less to go wrong, and if a display head does fail, information found on it can usually be obtained from another display head.

A rather remarkable convergence of practice with respect to display heads has taken place, and it is virtually certain that in the foreseeable future, sensor data will be displayed on a data head system comprising:

- A HUD, whose primary functions are flight control, weapon delivery, and forward-looking sensor display.

- A helmet-mounted display (HMD), whose primary functions are flight control, weapon display, and slewable sensor display.

- A vertical situation display (VSD) with much the same function as the HUD.

- A horizontal situation display (HSD) used for navigation, tactical situation display, threat analysis, and display of downward looking sensors.

These four display heads may be supplemented by advisory displays on either side -- a left situation advisory display (LSAD) would display downward looking sensors, navigation data, stores management data, display option lists, system status and activities, and threat analysis; and a right situation advisory display

(RSAD) would display energy management data plus engine status and activities.

Table 4.1-1, taken from Krebs et al., summarizes the functions of each of these display heads. Two aspects of that figure are especially important: the back-up functions (secondary functions) served by each display head (labeled DISPLAY in the table), and the image types (forms of information) for each display head. In the FDL simulation, any type of display (raw video, digitized data, symbology, or lines) must be displayable on any display head, simultaneously, and correlated in both space and time.

While the configuration of display heads treated in Table 4.1-1 is most directly applicable to single-seat tactical aircraft, and the pilot seat of tandem, two-seat tactical aircraft, display heads for the back-seater (or for other-than-pilot crew members of multi-seat combat aircraft, such as strategic bombers) will be composed of the same elements. Hence, for the purposes of this study, meeting the requirements for a single seat tactical aircraft will result in meeting the requirements for any aircraft.

The missions and mission segments described below are relevant in that they impose specific requirements on cockpit displays being simulated, such as the size and characteristics (terrain, cultural features, emitters) of the gaming area, the number density and characteristics of objects in that area, resolution, accuracy of alignment of different representations for the same object, etc.

The contents of the sensor displays can be categorized into the following five categories:

1) Terrain Data
2) Cultural Features
3) Ground Targets

DISPLAY	PRIMARY FUNCTIONS	FORMS OF INFORMATION PRESENTATION	SECONDARY FUNCTION
Head-Up Display (HUD)	o Flight control o Weapon delivery o Forward-looking sensor	o Alphanumeric o Symbolic o Sensor video o Direct view of outside world	Backup to HMD and VSD
Helmet-Mounted Display (HMD)	o Flight control o Weapon delivery o Slewable sensor	o Alphanumeric o Symbolic o Sensor video o Direct view of outside world	Backup to HUD and VSD
Vertical Situation Display (VSD)	o Flight control o Weapon delivery o Forward-looking sensor	o Alphanumeric o Symbolic o Sensor video	Backup to HUD, HMD, and HSD
Horizontal Situation Display (HSD)	o Navigator o Tactical situation o Threat analysis o Downward-looking sensor	o Alphanumeric o Symbolic o Sensor video o Projected map/digitized map	Backup to VSD
Left Situation Advisory Display (LSAD)	o Downward-looking sensor o Navigation data o Stores management o Display options lists o System status and activities o Threat analysis	o Alphanumeric o Symbolic	Backup to RSAD
Right Situation Advisory Display (RSAD)	o Energy management o Engine status and activities	o Alphanumeric o Symbolic	Backup to LSAD

Table 4.1-1 ADVANCED INTEGRATED DISPLAY SYSTEM (AIDS) FUNCTIONS

4) Airborne Targets

5) Symbolic Data

The following discussion treats the requirements for the amount and resolution of data in each category.

__Terrain Data__ - This must provide several types of terrain, ranging from mountains (e.g., Fulda Gap) to deserts (e.g., the Mideast) with the resolution determined by the sensor system being simulated.

__Cultural Features__ - These have to be compatible with the terrain selected; however, by judicious choice of terrain, requirements for cultural features can be minimized.

__Ground Targets__ - This represents a most important data category. Three of the crucial issues arising with respect to its simulation are:

1) What types of targets need be simulated? Moving vehicles (tanks, armored personnel carriers, and trucks) which have to be distinguished from each other by the tactical pilot, are required. Other tactical targets, such as SAM's and rivercrossing equipment, should be provided.

2) What is the minimum number of targets of each type that is required? In view of the possibility of engaging many ground targets during a single firing pass, several dozen vehicles may be required.

3) Is motion required of vehicular targets? Yes, because vehicle motion is used as aid to identification and as input for prioritizing.

Airborne Targets - Both aircraft and missile targets are needed. A total of six simultaneous airborne targets (aircraft, air-to-air missiles, and SAM's) would appear adequate for FDL's requirements.

Symbolic Data - The amount and kind of symbolic data shown are determined by the aircraft systems being simulated.

4.2 MISSION TYPES

Although the FDL will presumably be called on, as it has been in the past, to conduct a wide variety of experiments associated with the overall character of the laboratory, this study concentrated on purposes of those missions. More specifically this study considered mission elements and their inherent requirements such as:

1) Air-to-air, air-to-ground precision weapon delivery accuracy
2) TF/TA
3) Nap-of-the-earth (NOE)
4) Extended gaming areas
5) Performance variation (i.e., sub/supersonic regimes)
6) Environmental variations (visibility, etc).

The following paragraphs address these requirements from the point of view of real world or generic requirements. It should be noted that these will only serve as a basis of comparison in the parametric evaluation presented elsewhere.

4.2.1 Weapons Delivery and Accuracy

Air-to-ground weapons to be employed in planned FDL studies are those currently in the inventory and evolutionary developments of them. Delivery accuracies range from circular error probabilities (CEP) of 50 ft for conventional "iron bombs" to CEP's of 5-10 ft for E-O guided and 2-5 ft for laser-guided weapons.

4.2.2 Terrain Following and NOE

It is anticipated that a substantial portion of the flight profile of air-to-ground missions will be flown at low altitude to avoid detection by enemy radar. Minimum altitude to be flown depends on the terrain and the threat, among other factors. It is probable that altitudes flown in combat will be substantially lower than those used, for safety reasons, in peacetime training. FDL may well wish to simulate such wartime altitudes. A good estimate of this minimum wartime altitude is 100 ft; an altitude of 50 ft is well within the range of possibility, especially where the terrain is flat and enemy defenses strong.

If only peacetime altitude minima need to be simulated, 200-250 ft would be adequate.

4.2.3 Gaming Areas

Since the typical radius (take-off to weapons release) of air-to-ground missions is approximately 300 mi, with maxima in the 500 to 700 mi range, the gaming area provided should be about 500 by 500 mi if such mission simulation, including gross departures from planned flight paths, is required. However, a significant cost element is a function of the size of the gaming area, and hence considerable economies might be achieved by using 500-mi long corridor, rather than a 500 mi square. Such corridors would have the following properties:

a) Their width would not necessarily be uniform along the track (or from one corridor to another), but would vary with the maximum altitude likely to be flown at any point.

b) Their length would not be a uniform 500 mi but would be tailored to specific experiment/mission requirements.

c) To cope with departures from the planned flight path, one or more of the following approaches can be taken:

1) A forking corridor can be included where there is a reasonable expectation of a change in heading.

2) The corridor can be widened where there is a reasonable expectation of an increase in altitude, or a moderate departure from the planned flight path.

3) Image detail can be increased when there is a reasonable expectation of a decrease in altitude.

4) The experiment can be aborted if the simulator aircraft departs too far from the anticipated flight path.

5) The amount of terrain detail provided will generally be uniform across the width of the corridor, but can vary along its length to meet specific mission requirements and altitude expectations.

6) To compensate for learning effects and to enable more confident generalization from experimental data, several versions of each corridor can be used. To some extent this corridor redundancy can be reduced by flying a given corridor in both directions.

The economies made possible by the use of the corridor approach place a burden on the experimenter in that he or she must define the mission and the experiment before incorporating it in reasonable detail the production of corridor imagery. With a square gaming area, such preparation is not needed, assuming that

provision for meeting all probable imagery requirements is built in.

Whether the square or the corridor approach is taken, a variety of terrain is required, including at the typical European terrains (wooded, hilly to mountainous) and Near Eastern geography (desert).

4.2.4 Environmental Conditions

The degradation of various sensors (including the human eye) by such environmental conditions as darkness, clouds, fog, rain, ice, and snow needs to be simulated. Effects need not be simulated for each combination of sensor and environmental condition; for example, lasers are not affected by darkness, and certain laser frequencies are not attenuated by water vapor.

4.2.5 Sensor Parameters (accuracy, FOV, etc.)

The characteristic values of the parameters of each sensor must be appropriately simulated so that the task loading and system performance in the simulator can be generalized to aircraft situations.

For imaging sensors, the modulation transfer function (MTF) curve and FOV must duplicate real-world values; for range finders, accuracy, variability, and beam width effects must be duplicated. Tolerances on these variables should be sufficiently tight so that the sensor's outputs seem correct to the pilot (or other crewman), and provide him with the same level of task loading and the same total system performance level.

Applying these criteria to the wide FOV sensor of the LANTIRN system (similar considerations apply to its narrow FOV sensor designed to detect and track "hot" surface targets), the display

system should be identical to the real-world system for such parameters as brightness, resolution, and FOV. It may well be desirable to use the actual LANTIRN display system, driven with a simulation-derived signal. That signal, the output of the image generation system, needs to provide resolution, SNR's, and imaging content meeting the requirements for imaging sensors discussed in the previous paragraph.

4.3 EXISTING SYSTEM CONSIDERATIONS

In order to evaluate the advanced sensors described earlier, a total mission simulation with the pilot in the loop must be provided. Such simulation must provide a realistic context for tasks involving these advanced sensors, duplicating the task loading that would prevail in the aircraft. An important element in this task loading requirement is the simulation of the out-the-cockpit view. Such visual simulation must are high fidelity to assure that visual tasks, such as acquisition and identification of ground targets, are of realistic difficulty. The effect on task loading of inappropriate fidelity -- such as with a digital system lacking sufficient edges to embed the target in realistic visual "noise", or with a camera-model system (CMS) providing insufficient detail, and hence permitting target recognition only at much closer than real-world distances -- can lead to loss of confidence in the results of studies employing these advanced sensors.

While camera-model visual systems can provide the needed fidelity over parts of the mission spectrum, they have critical limitations in the low-altitude regime, as the diffraction effects inherent in a probe lens of a small enough size to permit low altitude simulation with a reasonably scaled modelboard preclude such a lens from providing needed resolution. If the diffraction effects were minimized by using a larger lens, the probe containing that lens could not get sufficiently close to the model board to

simulate the low altitudes at which many of the radar-avoiding air-to-ground missions are flown. Section 6.3.2 discusses the tradeoffs involved, and Figure 6.3.2-1 plots the diffraction-caused resolution limits versus lens size limits on minimum altitude for each of several modelboard scales. It should be remembered that the theoretical values shown in the graph are optimistic in that resolution is degraded by factors other than diffraction, and the edge of the hypothetical probe lens cannot be allowed to actually touch the model board.

Thus, with a CMS, a realistic air-to-ground mission can not be simulated in its entirety, although parts of it could (e.g., relatively high altitude cruise, a modelboard representing only a small ground area, a few seconds before and after weapons release).

CIG systems do not have the depth-of-field problem, diffraction limits on resolution, and modelboard size related restrictions on gaming area intrinsic to CMS's. Whereas the performance of camera-model systems is largely limited by the laws of physics, that of CIG systems is limited by technology and dollars, and as digital technology continues its rapid improvement with time, a given budget will be able to purchase increasingly capable systems as the year of delivery advances to 1990, 2000, and beyond.

For the forseeable future, however, CIG systems will have a much more limited number of pixels per frame or per arc min^2 than do CMS's. In order to evaluate the effect (on task performance, task loading, etc.) of the limited number of pixels available, one must first optimize the use of the pixels that are available.

The scarcity of pixels in current (and forseeable) CIG systems has at least two deleterious effects that are likely to affect the task performance and/or task loading of the pilot using

such a visual system for a task such as air-to-ground weapons delivery. First, because of limitations in the number of edges or facets that can be processed and displayed at any given time, it is necessary to model a given feature with an increasing number of edges or facets as it is approached and its angular subtense increases. Since this increase is necessarily discontinuous, the increased detail "pops out" as one nears the object, rather than increasing continuously and gradually, as in the real world. A second deleterious effect (this one not unique to CIG systems) arises from the fact that one of the cues to distance or altitude is that class of widely distributed features one can first distinguish -- blades of grass, leaves on a tree, branches on a tree, separate trees. If a visual system does not have sufficient resolution and detail which compromise the eyes' acuity, then this important cue is falsely presented, and the pilot must be much closer to the scene to perceive, for example, separate trees. In such a situation, he must not only place greater reliance on other distance cues, such as object size or streaming effect, but must discard the false cues -- a difficult action to take since this cue has been a firmly established part of his behavioral repertoire.

In order for CIG systems to provide the same task difficulty and task loading that is present in the real world, these two consequences of the pixel shortage must be overcome. The "popping out" of objects (or object detail) can be minimized by modeling small increments in detail between various versions of features, and assuring that features do not disappear once they "pop out" with normal forward-looking, forward moving flight. Duplication of the "I must be x meters from that forest now because I can just distinguish its individual trees" phenomenon requires both a high system resolution and a sufficiency of individual trees, branches, and leaves. It is not known at this time whether these details can be adequately provided through texturing techniques, or whether facets will be required.

4.4 DESIGN REQUIREMENT CONSIDERATIONS

Several points should be considered prior to exploring technical solutions to the problems discussed above. There are three points of relevance that will assist in developing the concluding recommendation of this study.

First, as previously mentioned some latitude can be taken in the evaluation of the facility requirements and later in the design, structure, and reality of the experiments. This will allow researchers to perform experiments in a laboratory environment and derive valid results. This facility is intended for research in specific man-in-the-loop experiments. For the short-term plans (cruise and navigation exercises notwithstanding), mission capabilities can be narrowed. For example, this concept allows the facility designs to develop capabilities related to specific needs singularly rather than on a continuum. Thus, for cruise-oriented experiments the design is permitted to suggest multiplexing sensor displays with separate image generators: CMS for take-off, landing, etc., and CIG for cruise. This flexibility permits construction of a creditable system even though simulation technology SOTA does not permit the design of a single system to satisfy all needs.

The second consideration of note for the facility design is that the specific parametric needs (Section 4.2) derived from real world missions need not be reproduced 100% in order to develop a creditable system. There is also great advantage to the facility designer in that SOTA trends in sensor displays are directed towards the synthetic image. Thus, the requirements to simulate high resolution detection equipment are minimized due to the technique used to display the information to the pilot. This does not alleviate the problem of placing and detecting elements in the operating environment, but it does reduce the difficulty for elements of concern (targets, emitters, etc.).

The third advantage for the facility design is related to the equipment used to provide the sensor displays. Since the SOTA for aircraft displays is tending toward synthetic video (raster and calligraphic) a generic system can be employed in the system. This system must be flexible (e.g. variable raster line rates), but can be used for a variety of applications. This is due in part to the similarity in design between real-world systems and potential simulation systems, i.e. each consists of display generators, memory, software, and display heads for mixed raster and calligraphic images.

Although the requirements placed on the FDL facility are extremely complex, the points outlined above will allow facility designers to develop a useable system.

5.0 SIMULATION, STATE OF THE ART, AND TRENDS

This section will discuss and evaluate all available image generation and processing techniques. Each, of course, offers advantages and disadvantages in sensor simulations. In this section, only the technical merits and limitations of each approach are considered. Later sections of this study will investigate how well each simulation technique solves the problems faced by FDL, how well it merges with existing hardware at FDL, and what potential each technique offers for expansions in anticipation of future sensor simulation problems.

5.1 IMAGE GENERATORS

5.1.1 Camera-Model System

This type of system has clearly established its usefulness and has become a major contributor to the art of simulation. In the context of this study, its importance is amplified by the fact that two CMS's are already part of the existing FDL facility and because the wealth and realism of details of certain sensor simulations point directly at the known advantages of these systems.

To understand these advantages and the equally well-defined disadvantages, this section presents the fundamental operating principles, lists some successful applications, and discusses the major system components which limit performance and application in general and more specifically in the realm of sensor simulation.

5.1.1.1 General Principles

The major components of a camera-model image generation system include:

1) A scale model of the terrain area

2) A bank of lights to illuminate the model
3) An optical probe which collects light from the point in the model space corresponding to the simulated observer's eyepoint
4) A closed circuit TV (CCTV) camera, which receives and image relayed from the optical probe
5) A gantry to position the probe and camera assembly to collect light from the correct eyepoint

In recent CMS's the models have been 24 ft wide by 64 ft long, standing on edge in a vertical plane. This orientation has distinct advantages for model and light bank access and floor space considerations and it also allows the gantry structure to carry the probe and camera across the length of the model, thus minimising bending moments on its structure. This gantry tower rolls on a horizontal track rigidly anchored to the floor. In principle, the model lengths can be made arbitrarily long (simply by laying more track for the gantry), but customer space limitations have held model length to 64 ft.

5.1.1.2 Modelboard

5.1.1.2.1 Model Size Consideration

Extending the model width beyond 24 ft, although not impossible, has major implications for the design of the structure and of gantry servos, and requires undesirable amounts of overhead building clearance. A serious consideration in sizing models is the power required for illumination. CMS's recently installed at Fort Rucker require 200 kW of power to illuminate a 24 by 64-ft model to a level of about 7000 ft-candles.

The area of a model of a given size may be use to provide coverage of a large gaming area at a low level of detail, or a smaller gaming area at a higher level of detail, depending on the

scale factor chosen. Rigid models have been made with scale factors ranging from 370:1 to 5,000:1. Given the real-world vehicle performance, the scale factor determines the required gantry servo accelerations and maximum and minimum gantry velocities (for smooth operation). The choice of model scale is strongly influenced by considerations of depth of focus in the optical probe and by minimum operational eyeheight requirements.

5.1.1.2.2 Special Paints

Selected objects on the modelboard are sometimes painted with pigments whose wavelength spectrums are inside or outside the visual spectrum but within the camera range of sensitivity. Such painting must be in compliance with paragraph 4.3.1.2 of the SOW.

Techniques for selecting these special paints fall into two distinct classes. When the paints are chosen by passive methods, they are chosen to be optimized for the particular sensor system or portions of the spectrum (for which the balance of the system chain yields effective results). The disadvantage of such methods is that they limit the system to a narrow range of sensors centered on one frequency band. Active methods, on the other hand, modify the model or paint characteristics by exitation from an outside source. One example of this is application of heat to selected areas of the model via embedded electrical resistive elements.

In the field of camera model simulation very little work has been done in testing paints for reflectivity and absorptivity at wavelengths outside the visual spectrum. However, during the production of the 2B-31 helicopter simulator program some testing was done to pick the paints that suited Link's Probe Height Sensing IR emitting assembly. The tests established paint surfaces that reflected a minimum of 35% in the 8400-8500 nmi range. A listing of these paints is on file at Link.

Link has attempted to paint selected objects with special pigments to emphasize protrusions and shapes that should be recognized through the display system. The testing was done on the 2B-31 CMS and the method found to be ineffective.

Fluorescent paints were incorporated on the KC-135 aerial refueling prototype camera model system in 1964 and in the Strategic Air-to-Air Combat (SAAC) program in 1976. The paints were excited by ultraviolet incident radiation to a level where the continuous fluorescence of visible radiation was strong enough to be effectively picked up by the camera of the system. The SAAC system at Luke Air Force Base in Arizona is being used successfully as a target illumination subsystem in the simulator.

The U.S. Government is currently testing some paints that have absorption capacity in regions that could interfere with sensor detection (radar radiation region). No data is available at this time. It may very well be possible to modify existing terrain modelboards to simulate the desired sensor displays. Much work is being done by companies such as Martin Marietta, McDonnell Douglas Electronics, Northrup Corporation, and Texas Instruments.

Many of these companies are using techniques such as special target encodements with IR responsive paints, video processing, and other techniques to yield IR responses. The previously mentioned companies were contacted informally and were reluctant to discuss their work since most of this work consists of in-house development efforts to support aircraft and sensor development programs and all of the technology is proprietary with the company which has sponsored the development.

Discussions were held with Independence Scale Models Corp. of Philadelphia, PA. They were adverse to disclosing details of the methodology involved but were willing to disclose some of the characteristics of model systems that they produced involving active methodology simulating the visual and infrared wavelengths.

Independence Scale Model Corporation has completed the fabrication of Thermal Terrain Model #MT-168 with targets and controls for the U.S.A. Missile Command, Advanced Simulation Laboratory, Redstone Arsenal, AL 35809. Some specifications regarding their product are summarized in Table 5.1.1.2.2-1.

The three areas of electromagnetic radiation were controlled by color pigments for the visible, special pigments and illumination techniques for the near IR, and heating elements behind the targets for the thermal IR. All three areas were successfully used to test sensors.

In conclusion, this area shows some potential for simulation of sensors; however, the use of passive methods would require a significant amount of developmental activity, and the use of active methods would most certainly involve major modifications to the existing facilities.

Table 5.1.1.2.2-1 THERMAL TERRAIN MODEL MT-168

Area:	Test Area Three (3)
Scale:	1:500
Spectral Response:	Visual .4 to .7 microns Near IR .7 to 1.5 microns Far IR 3 to 15 microns
Targets:	Buildings, military vehicles (trucks and tanks)
Control:	A control console was provided which had individual controls and adjustments for terrain, water, and target heating.
Summary:	Thermal Terrain Model #MT-168 described above represented a portion of Test Area Three (3) Redstone Arsenal, Alabama. This 8 by 16 ft 1:500 scale model depicted real-world spectral reflectance characteristics in the visible, near IR, and thermal IR.

5.1.1.2.3 Target Scaling and Highlighting

The addition of target models at an exaggerated scale is a viable technique. This results in acquisition of the targets by the pilot at extended ranges, thereby circumventing the inherent resolution limitations of the closed circuit television and display systems in the simulation.

This can be a valuable technique in fairly wide field-of-view systems or in cases where weapon launch is at a range where a significant quantity of surrounding cultural detail is included in the scene. Because of the increased sizes of targets provided, the pilot may underestimate the distance to the target.

This technique was found to be very helpful in the case of the AH-1Q Cobra Simulator (Device 2B33) for tracking, optical, wire (TOW) weapon training. In this particular case a model scale of 1500:1 was used whereas the target scale was 500:1.

In conclusion such techniques are valuable but must be used with caution, since the selection of target scale is a function of simulator visual system characteristics, unique sensors required, and the mission being simulated. In general it would be a simple task to change target sizes on the model as a function of the mission scenario.

5.1.1.3 Illumination.

Ideally, the lighting for a CMS should have the following desirable characteristics:

1) High lumen efficiency (the light output (in lumens) per input electrical watt should be high)
2) Insensitivity of light output to increased temperature
3) Good color rendering

4) High optical delivery efficiency (the smaller the source, the easier it is to produce a fixture which delivers a high percentage of the lamp's light to the model surface)
5) Long lifetime
6) Good control of intensity (ideally the lights should be infinitely variable from zero to full brightness without introducing a color shift)

The types of light sources that can be considered to fulfill these requirements are listed in Table 5.1.1.3-1 along with their advantages and disadvantages. Historically, the fluorescent source was used almost exclusively by CMS manufacturers before the 1970's. With the advent of metal halide lamps, some manufacturers switched to metal halide while others stayed with fluorescent. For color CMS's, the clear superiority of metal halide over fluorescent and all other light sources is shown in Table 5.1.1.3-1.

The sodium vapor lamps (GE Lucalox, Sylvania Lumalux, and Westinghouse Ceramalux) are extremely efficient in terms of light output per electrical input watt. However, their yellow-orange characteristic color makes them totally unacceptable for accurate color reproduction in color CMS's. For a black and white CMS the excellent lumen efficiency of the sodium vapor lamps makes them the logical choice if the model is painted to reproduce the correct shade of gray with the yellow-orange illumination.

The clear metal halide lamps are good in all respects. The color rendering of the metal halide lamp can be improved slightly by using a phosphor coating, but this seriously affects the efficiency at which light can be delivered to the modelboard because of the large source size that is created by phosphor coating on the outer bulb.

Table 5.1.1.3-1 COMPARISON OF ILLUMINATION SOURCES

ILLUMINATION TYPE	EFFICIENCY (1) (lm PER ELECTRICAL INPUT W)	CONSISTENCY OF LIGHT OUTPUT WITH INCREASED TEMPERATURE	COLOR RENDERING	OPTICAL DELIVERY EFFICIENCY	LIFETIME(2) (HOURS)	CONTROLLABILITY OF INTENSITY(3)(4)
SODIUM VAPOR	130	Good	Poor	Good	10,000	100 to 30% immediately. 100 to 10% in 15 min. Dimming causes shift to yellow.
METAL HALIDE (CLEAR)	100	Good	Good	Good	10,000	100 to 34% immediately. 100 to 14% in 5 min. Dimming causes shift to blue.
METAL HALIDE (PHOSPHOR COATED)	100	Good	Good	Fair	10,000	100 to 34% immediately. 100 to 14% in 5 min. Good color stability throughout dimming range.
FLUORESCENT	84	Poor	Fair	Fair	18,000	Range unknown, should have good stability throughout dimming range.
MERCURY (PHOSPHOR COATED)	63	Good	Fair	Fair	24,000+	100 to 25% immediately. 100 to 2% in 20 min. Good color stability throughout dimming range.
MERCURY (CLEAR)	57	Good	Poor	Good	24,000+	100 to 25% immediately. 100 to 2% in 20 min. Dimming causes shift to blue.
INCANDESCENT	24	Good	Excellent	Good	1,300	100 to 0% immediately. Possible color shift.

NOTES:

(1) - Based on initial lumen output for 1000 W lamps except for fluorescent = 110 W size. Does not include ballast losses.

(2) - Based on 10-12 hours per start for 1000 W lamps except for fluorescent - 110 W size.

(3) - Based on 1000 W lamps except for fluorescent.

(4) - All sources are infinitely variable throughout the range indicated.

Fluorescent lamps are usable in terms of their color rendering characteristics but have two disadvantages. First of all, they are sensitive to heat. If a large number of them are put together for high illumination, then a special air ducting structure is required to remove the heat they generate in order to keep the lumen efficiency up. Secondly, the light is not easily directed by a reflector, and if used without reflectors theoretical considerations reveal that the illumination level they can produce on a modelboard in a practical system is no greater than 70% of the bulb wall brightness. Since the typical bulb wall brightness is 5000 ft-lamberts, this means the maximum illumination that can be achieved on the modelboard is no greater than 3500 ft-candles even if the lighting bank consists of flourescent bulbs touching together. This has been demonstrated by two systems built by Link. In one system 100 kW of fluorescent lights produced a 3000-ft-candle level on a 22 by 44-ft modelboard. In another system, 100 kW of clear metal halide lamps produced a 7400-ft-candle level on the same size modelboard, thus demonstrating the greatly superior optical delivery efficiency of metal halide.

The mercury lamps have just fair lumen efficiency. In the case of the clear mercury lamp, the color rendition is poor and although this can be improved by a phosphor coating, the optical delivery efficiency suffers.

Incandescent lamps provide excellent color rendition but their lifetime and lumen efficiency are very poor, thus eliminating them from consideration.

For camera-model work intensity control of the light sources discussed above has traditionally been done in discrete steps by shutting off a pattern of lamps on the light bank. This solves the problem of changes in color balance of the light source but does not allow for fine control of the intensity. Incandescent lamps can be controlled from zero to full brightness with Silicon

Control Rectifier (SCR) dimmers with some change in color balance. Ballasts and controllers which can produce changes in brightness throughout a limited range are also available for the discharge lamps of Table 5.1.1.3-1. However, except for lamps having a phosphor coating, there is a definite color shift when the lamps are dimmed. With dimming, the discharge lamps have a long-term range lower limit which is reached after the lamp temperature stabilizes (in 5-20 min, depending upon the type of lamp). This long-term limit is usually significantly lower than the limit which is reached immediately after dimming. Table 5.1.1.3-1 shows the immediate and long-term limits for 1,000 W lamps along with the response time to the long-term limit.

Future developments in lighting applicable to CMS's appear to be limited to further improvements on the existing light sources of Table 5.1.1.3-1.

5.1.1.3.1 Effects of High-Intensity Illumination

The use of small apertures of 1 mm or less has required very high levels of illumination (typically 7000 ft-candles for the systems built at Link in the last few years). Besides requiring large amounts of electrical power, these illumination levels are accompanied by thermal expansion problems in the rigid fiberglass terrain models (e.g., movement of as much as 1/8 in. perpendicular to the model surface due to buckling at points between support studs) and point fading. Model temperatures of as high as 120°F have been reached in a controlled ambient temperature of 66°F at the 7000-ft-candle illumination level. Models are subject to almost immediate damage if the illumination is increased beyond 10,000 ft-candles. This problem would be alleviated in a system which can use a larger aperture, since less illumination would be required.

The laser scanner system discussed in Section 5.1.4 eliminates the use of high model illumination levels. The camera system is replaced with a mechanical scanning system, but the probe hardware and its effect on system performance are quite similar.

5.1.1.4 Probes

Current CMS's are usually employed for visual rather than sensor simulation. As such the emphasis has been on generating wide field-of-view probes capable of close approach to the modelboard to permit NOE training and takeoff and landing exercises.

These requirements, of close approach and wide field of view, have dictated the direction of approach to probe design. The perspective point of an optical probe is its entrance pupil. This pupil, in order to achieve true perspective, must be at a distance from the modelboard equal to the simulated eye height divided by the modelboard scale factor. Typical modelboard scale factors range from 1500:1 to 3000:1. To simulate takeoff and landings and NOE flight, therefore, requires that the entrance pupil achieve a close approach to the modelboard. Ideally the pupil should be external to the probe. An additional problem at low altitude is that of adequate resolution over the entire ground plane. Scheimpflug probes have been developed to provide increased resolution of the ground plane at simulated low altitudes. Depth of field and Scheimpflug probes are described in section 5.1.1.4.2. To achieve a constant image size for constant field angle imposes another constraint on the pupil. A telecentric objective lens is required to ensure the constant image size for all simulated slant ranges. A telecentric lens has its aperture stop, or image thereof, located at the front focus. Therefore, the entrance pupil must at the front focus and ideally external to probe optical ele-

ments. These constraints on the pupil location, in conjunction with the wide field of view, limit the attainable performance.

Tilt lenses or Scheimpflug probes (see Section 5.1.1.4.2) have been developed which achieve improved resolution in a plane when low altitudes are simulated. These probes introduce additional design problems. Ideally the tilting lens relay cells should have zero principal plane separation to keep the image from shifting with tilt. The relaying of pupils from one tilting lens stage to the following tilted stage is difficult. Dynamic field lenses, which frequently have been unreliable in performance and nonrepeatable in their errors, have been used to relay pupils between stages. A Link-patented Revolutionary Scheimpflug Visual Probe (patent number 3,985,422 of October 12, 1976) eliminates many of the constraints of the conventional Scheimpflug probe design.

A fish-eye wide-angle lens was used as the objective lens in a probe built by Dalto Electronics. Fish-eye lenses are characterized by large diameter elements and an internal pupil. These lenses have large distortions and require complex raster shaping techniques to produce a final undistorted image. The internal pupil and large diameter make them unsuitable for applications where close approach to a terrain model is required.

5.1.1.4.1 Optical Considerations

Difficulty arises in keeping the entire scene acceptably in focus at the same time when foreground objects are very close to the probe, either because real-world objects are in the scene very close to the simulated vehicle, or because the real-world dimensions are reduced by a very high scale factor. A person familiar with photography would immediately think of "stopping down" the probe to increase depth of field. Figure 5.1.1.4.1-1 shows the geometrical basis for this approach to controlling depth of focus.

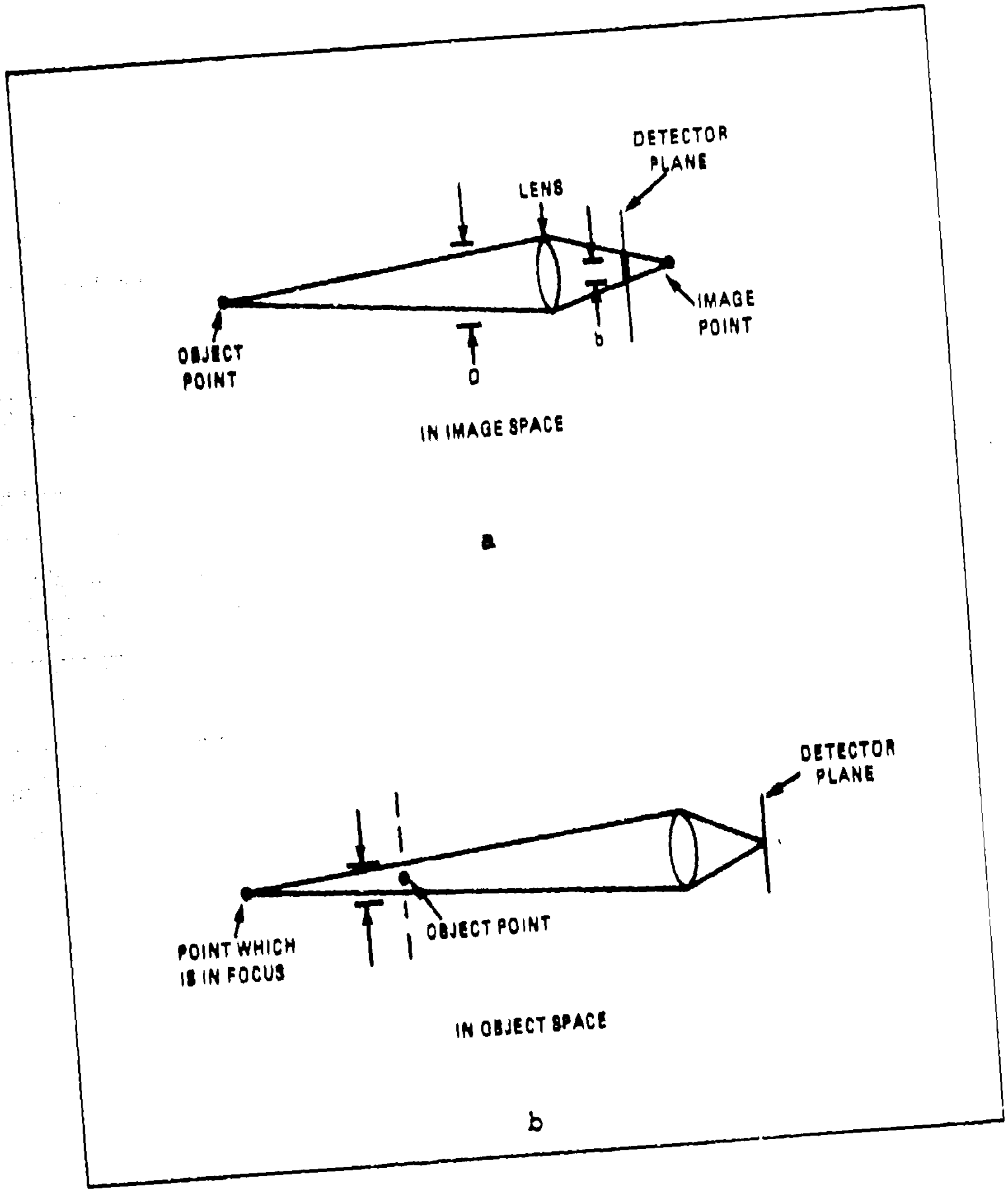

Figure 5.1.1.4.1-1 GEOMETRICAL ANALYSIS OF DEPTH OF FOCUS

If the image detector is placed where distant objects are imaged, then nearer objects will be in sharp focus on a plane lying behind the image detector, and light which would focus to a point on that plane is blurred over a circle of diameter b when intercepted by the image detector. The diameter of this circle is defined by the intercept of the rays from the outer edge of the lens on the detector plane as they converge toward the image point. It can be seen that the amount of blurring is proportional to the diameter of the lens.

Hence, one might suppose that if a certain diameter lens gave satisfactory depth of focus in a real-world situation, then, if the probe in the simulation visual had an aperture no larger than the diameter of that lens divided by the scale factor, equivalent depth of focus and resolution would result. However, when the wave nature of light is accounted for, light which is predicted by geometrical optics to be imaged to a point (as shown in Figure 5.1.1.4.1-1a) is in fact blurred by diffraction. The amount of the blurring is great enough so that an in-focus image gives the impression that the point in object space is spread so as to subtend an angle (in radians) of approximately λ/D (where λ is the wavelength of light) when viewed from the lens entrance pupil. This blurring affects the entire picture, not just the objects which are much nearer or further from the chosen focus distance. The total blur will be greater than the larger of the two blur terms (geometrical and diffraction) but less than the sum. The geometrical analysis encourages the reduction of aperture, but from the standpoint of diffraction alone, the aperture should be as large as possible. Clearly, there is an optimum aperture when both defocus and diffraction are considered, for which the geometrical effect of defocus (for objects at the extreme near and far ranges) and the effect of diffraction are of comparable magnitude (see Figure 5.1.1.4.1-2).

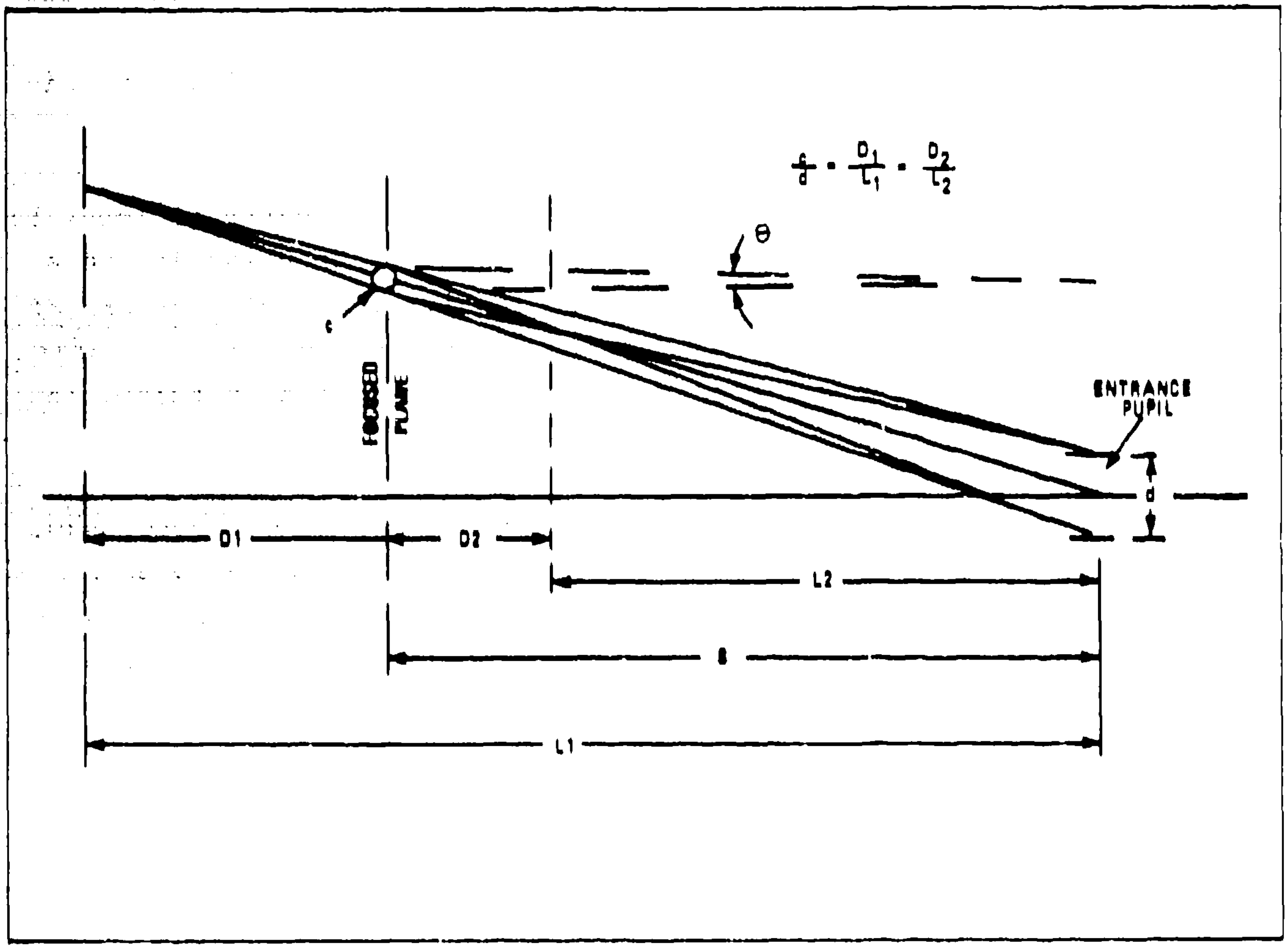

Figure 5.1.1.4.1-2 LIMITATIONS OF DEPTH OF FIELD

In general, this optimum aperture has fallen in the 0.5-1 millimeter range. It is instructive to compare λ/D for these applications with the angular resolution limit imposed by the TV raster. These have been mostly 60° diagonal systems, with 36° degrees appearing across the height of a 1000-line raster. Allowing for a 0.7 Kell factor, the resolution limit is at a spatial frequency of one line pair per approximately 6 arc-min. The ratio λ/D, assuming a wavelength of 5500 A°, is 1.89 arc-min (after conversion from radians) for a 1 mm pupil, or 3.78 arc-min for a 0.5 mm pupil.

The 0.5-1 mm apertures thus give sufficient depth of focus to provide satisfactory imagery everywhere except when landing on a runway (real-world eyeheights of 6.5-10 ft, with scale factors of 1000:1 to 2000:1) or when simulating NOE helicopter flight. Here, the extreme foreground imagery, although objectionably fussy, is usable.

A larger aperture might be appropriate for camera-model simulation of a sensor which puts a 3° diagonal field of view on a 650-line raster (TV limit at less than 1/2 arc min), particularly if the sensor is not used at extremely low altitudes (e.g. when weapons delivery rather than landings is being simulated).

The following discussion and Figure 5.1.1.4.1-2 show the relationships between pupil diameter, resolution, and depth of field.

The probe is focused on a plane at an object at a distance S. Objects in this plane will be sharply imaged. An object point lying beyond or nearer than this focused plane is seen by the lens as a small circle of confusion of diameter C. The probe images this circle as if it were a real object lying in the focused plane. The limit of acceptable depth of field will be reached

when this circle of confusion becomes large enough to subtend a prespecified angle (θ) at the entrance pupil.

$$c = S \cdot \theta \text{ (since } \theta \text{ is small } c \cong S \cdot \tan\theta)$$

$$D_1 = \frac{S \cdot c}{d-c} \qquad D_2 = \frac{S \cdot c}{d+c}$$

$$L_1 = S + D_1 \qquad L_2 = S - D_2$$

The limiting angular resolution (θ_L) is a function of the wavelength (λ) and entrance pupil diameter (d).

$$\theta_L = \frac{\lambda}{d} \text{ rad} \qquad (\lambda \text{ and d same units})$$

For $\lambda = 0.54607$ microns

$$\theta_L = \frac{1.87725}{d(mm)} \text{ (arc min)}$$

We want θ to be small (for good resolution) and D_1 and D_2 to be large (for large depth of field), but both are inversely proportional to d, so the value of d must be a compromise. The relation between θ and d for a fixed wavelength is illustrated in Figure 5.1.1.4.1-3.

5.1.1.4.2 <u>Depth of Field and Scheimpflug Probes</u>

A special optical technique is sometimes valuable to accommodate extremely low-altitude eyepoints. For example, when an aircraft is approaching or standing on a runway, the runway should be

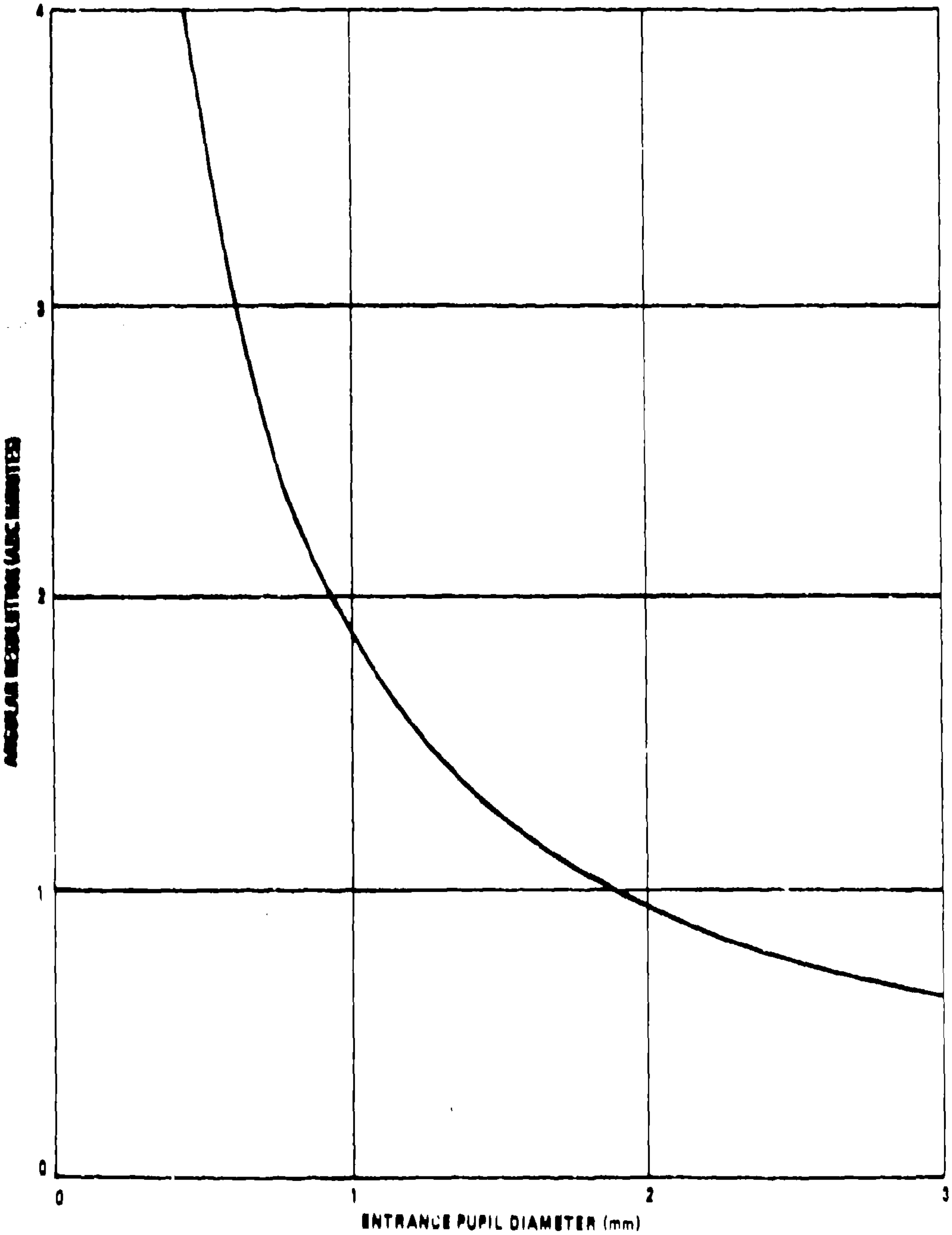

Figure 5.1.1.4.1-3 ANGULAR RESOLUTION (ARC MINUTES) VS ENTRANCE PUPIL DIAMETER (mm) FOR WAVELENGTH = 0.54607 MICRONS

in focus from the very near foreground at the bottom of the pilot's window to the end of the runway, a relatively large distance away. With a conventional probe, the plane of best focus in object space is perpendicular to the probe's line of sight, which is typically horizontal. By adding intermediate aerial images to the probe optical layout and tilting the relay lenses, the plane of best focus for a horizontal line of sight, normally vertical, can be transformed to coincide with the plane of the runway. The tangent of the lens tilt angle required to accomplish this transformation is inversely proportional to the probe eye height above the runway and to the probe pitch angle. If the scene consists of flat terrain and the flat runway, one obtains the appearance of infinite depth of focus, from the foreground out to the horizon. However, as before, focus degrades for objects extending perpendicularly to the plane of best focus. Although the entire runway is in focus, vertical objects such as towers and poles will appear progressively fuzzier as they rise above the runway. The region of good focus is thinner for more extreme lens tilts (i.e., correction for lower eyepoints). The most recent generation of tilt-lens or Scheimpflug probes, built for Link by Farrand Optical Co., Inc., corrects runway focus fully down to 3-mm eye height above the model.

5.1.1.4.3 Probe Mechanisms

Probe pitch devices are of two types: single-reflection (Figure 5.1.1.4.3-1a) and double-reflection (Figure 5.1.1.4.3-1b). Single-reflection pitch has been more commonly used at Link because most applications in recent years have required very low eyepoints to be simulated, and have not required a wide range of pitch. Single-reflection pitch devices can be designed with a closer approach of the pupil location (eyepoint) to the model surface than double-reflection designs if the pitch range is moderate, but cannot provide pitch down to the nadir. Recent

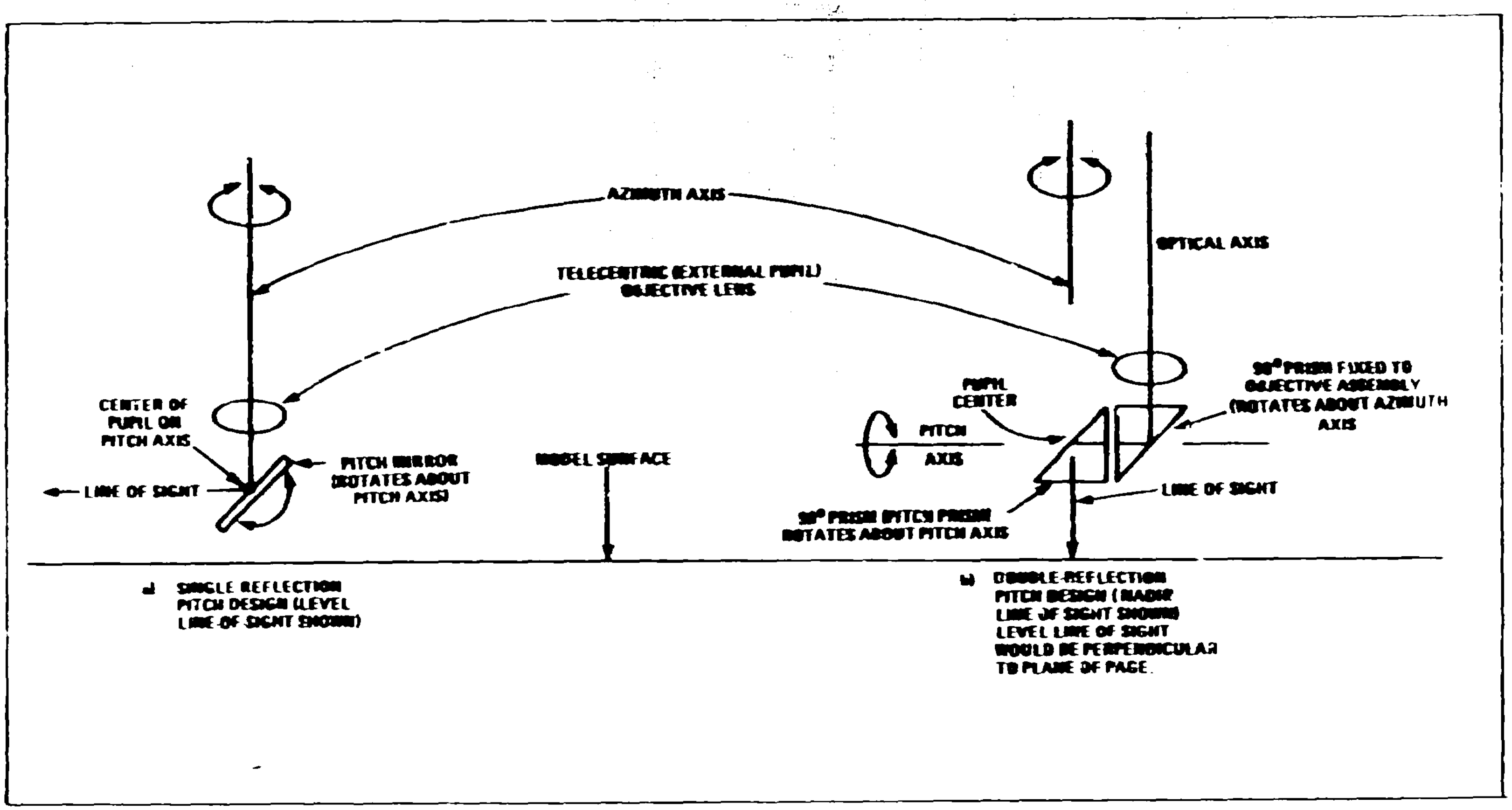

Figure 5.1.1.4.3-1 SINGLE AND DOUBLE REFLECTION PITCH DESIGNS

designs used at Link provide for eyepoints down to 1.9 mm from the model, with a pitch range from +25° to -40°.

For systems with less severe minimum eye height requirements but requiring pitch to nadir, Link has supplied probes with double-reflection pitch mechanism (e.g., the Apollo Lunar Module Simulator (delivered in 1966), and the Orbiter Aeroflight Simulator (1975)). These probes also had wide-field objective lenses of 100° and 126° diagonal fields, respectively. The Orbiter Aeroflight Simulator probe allowed eyeheight approach to within about 4.5 mm and had pitch capability to full nadir from +30°.

Both types of pitch design result in image rotation as heading is driven. This must be compensated by driving an optical derotator, which is also used to introduce a rotation to simulate vehicle roll. In addition, the double reflection design rotates the image as pitch is driven, so that the derotator drive must also depend on pitch.

5.1.1.4.4 Probe Optical Axis Pointing Considerations

Probe line-of-sight pointing accuracy is affected by a combination of effects:

1) Bearing imperfections
   a) Pitch axis
   b) Heading axis
   c) Derotator axis

2) Backlash
   a) Pitch drive
   b) Heading drive

3) Alignment errors

a) Heading axis to optical axis (although Figure 5.1.1.4.2-1B shows optical axis displaced from heading axis, it is returned to the heading axis by some displacement optical folds not shown here)

b) Derotator axis to optical axis

c) Derotation optical components to derotator mechanical axis

The combination of all these effects produces line-of-sight deviations of the order of magnitude of 40-50 arc-minutes without correction. A probe with errors of this magnitude has been compensated for by software. The errors were calibrated and stored in a table as a function of heading, pitch, and derotator orientation. The software made interpolations between values looked up in this table, and applied additive corrections to the pitch and heading drive commands. This method produced a corrected line of sight within 7-8 arc-min error. This calibration accounted for all errors except backlash. Presumably the calibration could be refined to account for backlash by keeping a history of the last direction each axis had been driven, so as to reduce the error further, but this was not done, as the results were adequate for the application without this refinement. However, the error calibration did not hold its validity over extended periods of use and had to be recalibrated frequently. This experience suggests the desirability of a feedback scheme in which error is detected continuously by monitoring displacements of the images of reference points on the model.

5.1.1.4.4.1 Probe Pointing System

One probe with such a feedback system is the Aviation Wide Angle Visual System (AWAVS) probe delivered by Link to Naval Training Equipment Center (NTEC). This probe covered a maximum of 60° field and incorporated a zoom lens which reduced the field of

view to approximately 16°. See Figures 5.1.1.4.4.1-1 and 5.1.1.4.4.1-2 for the block diagram and optical schematic.

Optical filters separate the laser signal from the background. The laser signal is imaged onto a detector array that supplies information to the probe pitch and heading servos to correct pointing errors. For the large field (60°), the detector resolution is ±2 min. As the zoom power changes and the field is reduced the resolution improves to ±0.5 min per element. Sensor simulation does not require wide fields of view, nor low-altitude simulation in general. Therefore, two constraining parameters are eliminated if a new probe were to be designed expressly for sensor simulation applications. The maximum field could be limited to about 20°, and with a smaller field of view required, the probe design becomes easier. Improved resolution and reduced pointing errors are well within the state of the art.

5.1.1.5 Scan Lines and Bandwidth

In a television system, horizontal resolution and vertical resolution are equally costly in video bandwidth. That is, on the basis of a fixed bandwidth, the vertical resolution increases with the number of scanning lines and the horizontal resolution decreases a corresponding amount and visa versa. Furthermore, if a given increment of resolution is available for increasing the quality of a picture which originally had equal vertical and horizontal resolution, the quality will be improved more by applying the increment equally to the vertical and horizontal resolution than by applying it to improve resolution in only one direction. This conclusion follows from the known equality of the acuity of the human eye in various directions and the random orientation of the subject matter transmitted. Hence, the optimum use of the transmission band requires that the number of lines be near that number which provides equal horizontal and vertical resolution.

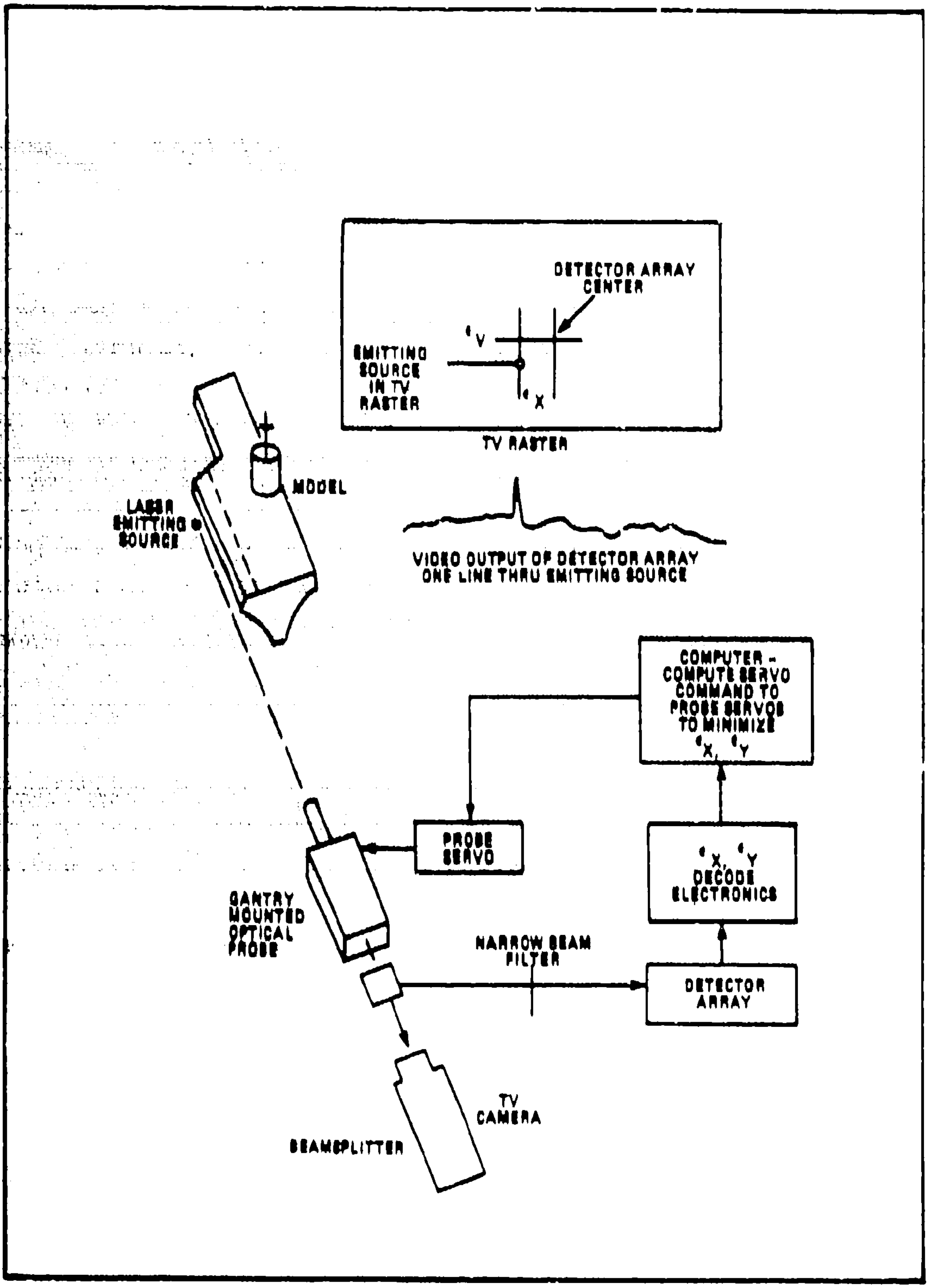

Figure 5.1.1.4.4.1-1 PROBE POINTING SYSTEM,
BLOCK DIAGRAM

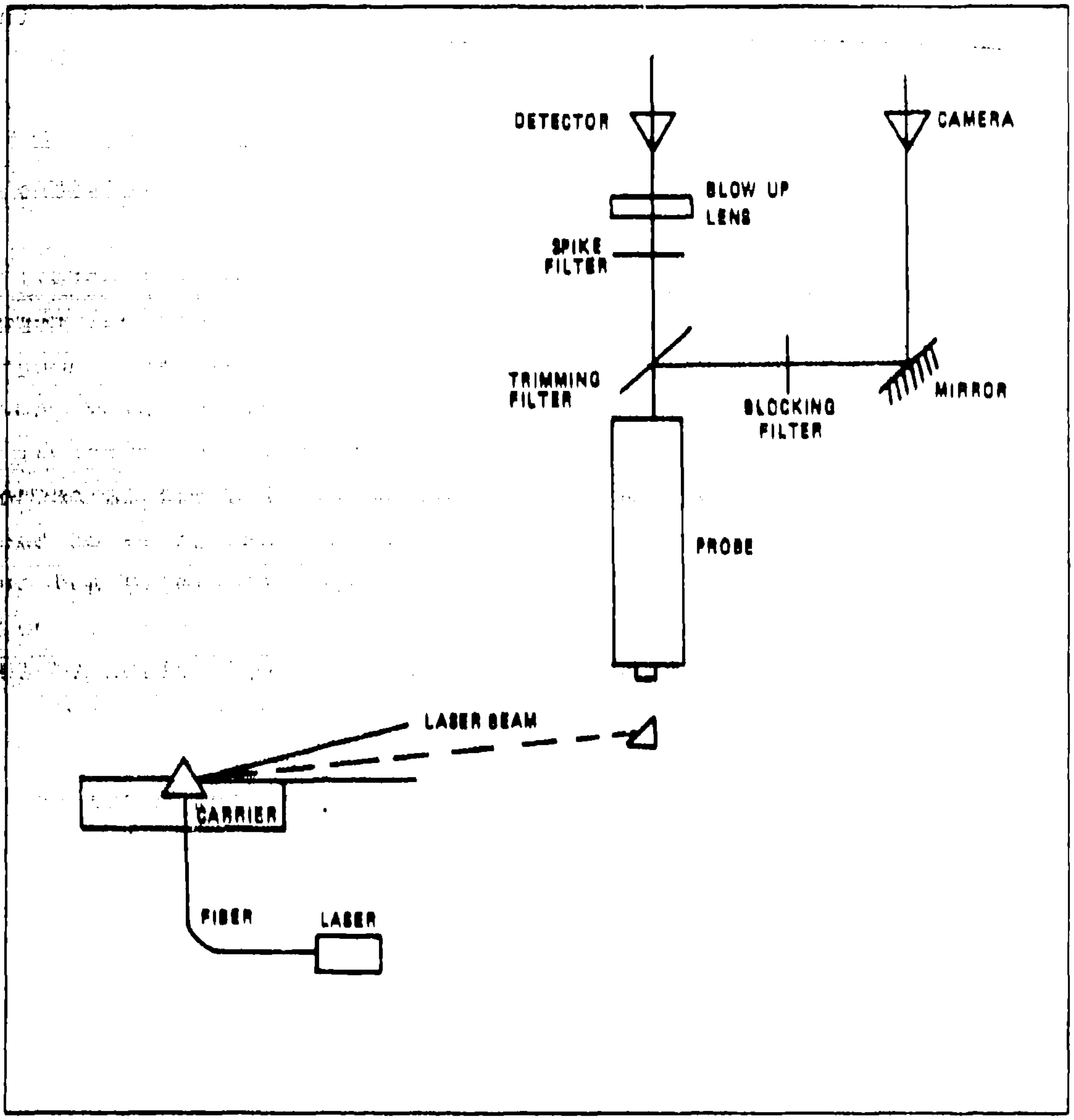

Figure 5.1.1.4.4.1-2 FRESNEL LENS OPTICAL LANDING SYSTEM (FLOLS) LASER AND TRACKER, OPTICAL SCHEMATIC DIAGRAM

The resolution capability of a video system is a function of the operating mode which is chosen during the design of the system and the performance of the various system elements. Of fundamental importance in setting the operating mode is the attainment of a high SNR, i.e., 40 dB or greater. Also, if the contrast of the object to be televised can be 100%, system performance will be maximized.

Choosing the scanning mode involves two separate decisions. First, the designer must choose the number of scan lines per picture (frame) in inverse proportion to the size of the detail to be reproduced. Second, the designer must choose a vertical repetition rate (in conjunction with phosphor persistence) fast enough to avoid flicker if human observation is involved, yet slow enough to keep within reasonable bandwidth requirements. The vertical rate can be chosen so that more than one vertical cycle is needed to scan the complete frame. In this mode, the scan lines of successive vertical cycles (fields) are interlaced spatially and the bandwidth requirement is less than for sequential scanning. However, in very high resolution systems, vertical resolution is degraded somewhat by interlacing.

The interrelation between bandwidth and scanning modes is described by the following formula:

$$\Delta f = \frac{\text{cycles}}{\text{active time}} \times \frac{\text{width}}{\text{height}} = \frac{\text{TV lines/height}}{2} \times \frac{W}{H} \times \frac{1}{t_{active}}$$

where $t_{active} = t_{line} - t_{blank}$

Thus for a given bandwidth of Δf,

horizontal resolution (TV lines/picture height) =

$$\Delta f \times \frac{2H}{W} \times (t_{active}).$$

The results of this formula are plotted in Figure 5.1.1.5-1. From this it may be seen that a higher scanning rate across a given pattern produces a higher frequency and a wider bandwidth is required. Also, the higher scanning rate means more lines per raster and allows a higher vertical resolution, typically to about 70% of the number of scanning lines.

Vertical resolution is described by the following formula:

$$\text{Vertical resolution} = (\text{number of active scan lines}) \times \text{Kell factor}$$

$$= \text{lines per frame} \times \frac{(\text{frame time}) - (\text{blank time})}{\text{frame time}} \times \text{Kell factor}$$

where the Kell factor is the fraction of the total number of scan lines which actually can be resolved.

In addition to the limits imposed by the chosen scanning mode and the available video bandwidth, there are finite limitations of other elements in the TV system. These include:

1) The diameters of the electron beams in the image pickup sensor and in the image display CRT

2) Image spreading in the image pickup sensor itself (e.g., by lateral charge leakage in a vidicon photoconductor)

3) The equivalent aperture of the optical lens in the system

4) SNR

5) The bandwidth of the CRT circuitry

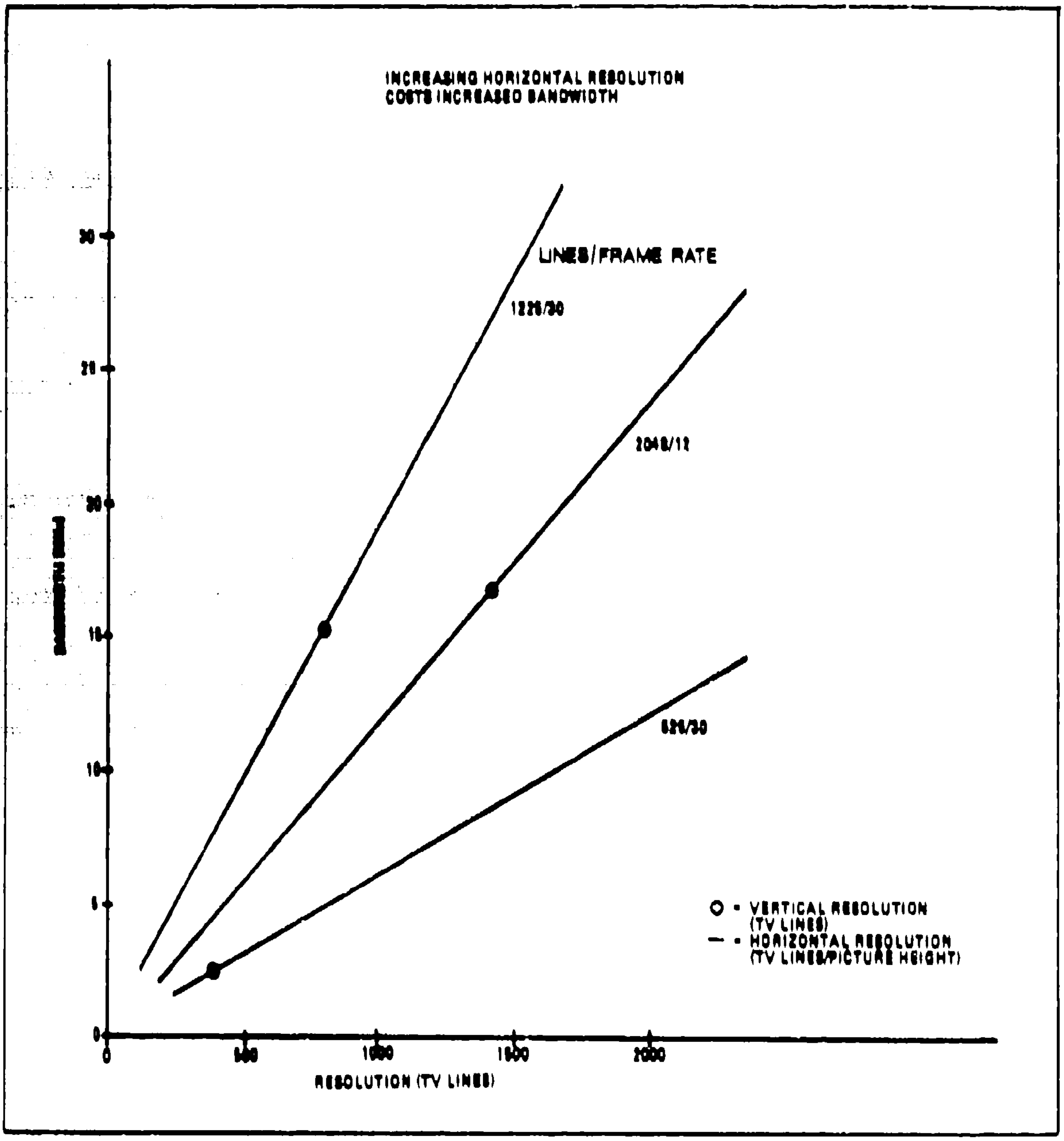

Figure 5.1.1.5-1 INTERRELATION OF SCANNING MODE, BANDWIDTH, AND HORIZONTAL AND VERTICAL RESOLUTION

Available systems are based on various sizes of image pickup tubes with various photosensitive surfaces. For applications where sufficient illumination is available, a vidicon is appropriate. Vidicons are available with useful photoconductor diameters of 2/3 in. to 4 1/2 in. and with various signal storage and lag characteristics. For applications where illumination is sparce, an Isocon or Silicon Intensified Target (SIT) image sensor may be used. Section 5.1.1.1 discusses various image tubes and their characteristics.

In a television system of constant line and field frequencies, line interlace of order greater than 2:1 offers an improvement in vertical resolution without an increase in video bandwidth.

The general idea of interlace is to lay down fields of N lines, but to displace successive fields by a fraction of a line pitch so that the gaps between lines are filled in. If one extra line is inserted in each gap, the result is the familiar 2:1 interlace. If two lines are inserted, the result is 3:1 interlace, and so on. The total number of lines in a frame or picture is increased by increasing the interlace order and hopefully the subjective vertical resolution of the system is improved.

2-to-1 interlace was adopted as standard early in the history of television and has been widely used ever since. Over the years, 3:1 and 4:1 interlace systems have been tried, but found to be unacceptable due to the objectionable large-area flicker, line crawl, and bright-dim line pairing phenomena. More development must take place in high-order interlace TV systems before its theoretical merits can pay dividends.

5.1.1.6 TV Image Tubes

Since the availability of the first TV camera tube, the trend has been to develop tubes with better resolution response and greater sensitivity, while operating at lower and lower levels of faceplate illumination, and while maintaining or improving the quality of the image. Due to the prolific development efforts of various image tube manufacturers, many generic tube types have emerged. Each type has a wide range of performance parameter variation and application. Some of these devices are compared in the following discussion. It is interesting to note that while electronic television has, from its beginning, depended on electron beams for picking up and reproducing the image, it now appears that self-scanned semi-conductor devices are beginning to carry out many of the functions of camera tubes.

Vidicon, SB_2S_3 (Sulfide) - The standard vidicon tube use an antimony trisulfide target and is the most widely used for closed circuit surveillance and general TV applications. It is basically a high resolution device and is available in various sizes from 1/2 in. to 4 1/2 in. diameter faceplates, resolution being proportional to size.

Its spectral response covers most of the visible light range and most closely approximates the human eye. A useful feature of the vidicon is the controllability of the target voltage to permit variation of tube sensitivity with light range. It can produce useful information at scene illumination levels ranging from 1-10,000 ft-candles. The tube's spectral sensitivity extends from 300-800 nm, peaking out in the green spectrum, but is lower in sensitivity than other tubes. It requires light levels approximately the same as normal room lighting. The major disadvantage of the vidicon is that its photo-conductive target exhibits some lag or stickiness which limits its dynamic resolution. This lag characteristic is a function of light level; hence, dynamic reso-

lution is poorer at low scene illumination levels. The amount of lag increases as illumination decreases because of the lower voltage excursion across th vidicon target which exists under these conditions. Hence, dynamic resolution, the ability of the vidicon to distinguish fine detail under conditions of motion, will decrease as illumination decreases. Other disadvantages of this tube are its dark current (a function of target voltage) which leads to shading problems, its image blooming characteristic when subjected to highlights and point light sources, and its tendency for image burn-in from intense light.

Its gamma of 0.7 provides an advantage in minimizing the amount of artificial gamma correction required in a TV system; the less artificial gamma correction a system uses, the better the SNR becomes.

Silicon Diode Array (SDA) - The SDA is made up of a mosaic of light sensitive silicon material and is approximately four times as sensitive as a sulfide vidicon. Other advantages are its broad spectral response (380-1200 nm), low dark current, high resistance to photo-surface burn, good SNR, and a reduced blooming target. Its infrared sensitivity makes the tube very useful for detecting hot objects of IR illuminated scenes.

The SDA's sensitivity makes it useful for operating over an illumination light range of 0.1-5,000 ft-candles. Unfortunately it does not have the capability for automatic sensitivity control the means of signal electrode voltage regulation as does the SB_2S_3 vidicon. Consequently, an alternate scheme of light level control is required, such as an automatic servo iris. Its lag characteristic is better than the SB_2S_3 vidicon, but not as good as the Lead Oxide tube (to be described). Its dark current is lower than the SB_2S_3 vidicon, thus providing better shading characteristics, but its limiting resolution of 800-1000 lines is not as good as the 1000-1200 lines for the 1 in. SB_2S_3 vidicon. The SDA has a linear signal output vs. light input characteristic. Thus, its

gamma is 1.0, resulting in the need for an artificial gamma correction circuit, and the inherent SNR degradation.

The SDA is available in target diameters of 2/3 in. to 1 in.

Newvicon. The Newvicon was developed as an improvement over SDA tubes. Its cadmium and zinc tellurides target material provide a sensitivity of approximately 20 times that of the SB_2S_3 vidicon. Other advantages over the SB_2S_3 are no blooming of high brightness details, freedom from image burn-in, and low dark currents. It is available in both the 2/3 in. and 1 in. diameter targets.

The Newvicon's static limiting resolution is approximately 800-900 TV lines while its dynamic resolution is limited by a lag characteristic similar to the SB_2S_3. Its spectral sensitivity range covers from 400 nm to 850 nm, making it useful for applications in the near IR region. Its gamma is 1.0 like the SDA, but its dark current is less.

The Newvicon operates in a manner very similar to the SDA in that it uses a fixed target voltage and must use an auto iris lens system.

Lead Oxide (PbO) - The PbO target is a high resolution tube with an excellent lag characteristic, better than any image tube previously mentioned. The tube is used primarily in broadcast cameras where low-lag, low dark current, low burn-in and low shading characteristics under normal lighting conditions are required. It is available in target sizes ranging from 2/3 in. to 30 mm diameters. Its gamma is 1.0. By design, it does not permit automatic sensitivity control by means of regulating the signal electrode voltage. Like the SDA and Newvicon, it requires an automatic lens iris system to accommodate varying scene illumination levels.

The resolution characteristics of the PbO vary from 800 to 1400 TV lines depending on target size.

The more recent versions of PbO tubes are being supplied with diode gun construction rather than the more conventional triode gun which results in lower lag performance. Use of the diode gun narrows the velocity spread of the electrons in the beam, thereby reducing the beam resistance and shortening the lag.

Saticon - The Saticon is a type of vidicon tube with a Selenium-Arsenic-Tellurium photoconductor. The tube was developed specifically for small, high-performance color TV cameras, but has proven useful for many other applications. The photoconductor represents an improvement in resolution, stability, and reduction of optical flare over the currently-used PbO photoconductors. Its sensitivity is comparable.

The photoconductor of the Saticon has a linear light-transfer characteristic; i.e., gamma is unity over the useful range of signal current. Its dark current is extremely low.

The high optical absorption and low reflectance of the photo conductive layer used in the Saticon are of particular importance. Since very little light is reflected back into the optical system from the photoconductor, the contrast and color fidelity of low lights in the picture are not degraded. The benefit of the high optical absorption characteristic is that very little light is dispersed through the photoconductor which could degrade its resolution characteristics as compared to PbO tubes.

Lag in the Saticon is caused primarily by the storage capacitance of the photolayer in series with the effective beam resistance.

The lag is minimized by using a low-beam-impedance gun and by using biased lighting to minimize photoconductor storage capacitance. Consequently, its lag characteristics are better than that of the PbO tube.

The Saticon is available in 2/3 in. and 1 in. versions having limiting resolution of 550 lines and 800 lines respectively.

Silicon Intensified Target (SIT) - The SIT utilizes an image intensifier coupled to a silicon faceplate vidicon, resulting in a sensitivity 500 times that of a standard SB_2S_3 vidicon.

The intensifier multiplies the light before it strikes the silicon target area of the vidicon. The amount of light amplification through the intensifier can be controlled by regulating the voltage between the phosphor screen and the photo cathode. Dynamic range of the tube may be varied in this manner and when coupled to a servo iris lens with a variable attenuation spot filter, the resulting dynamic range may be as high as 5,000,000:1. The SIT will produce a usable picture with as low as 2×10^{-2} ft-candles of faceplate illumination and still maintain an acceptable SNR.

The resolution capability of the SIT tube varies from 700 to 1000 TV lines depending upon bulb size which is very significant in low light level operation.

The SIT tube exhibits no photoconductive lag but there is some capacitive lag resulting from the finite time it takes for the electron beam to remove accumulated charge from the target. Lag in this tube is inversely proportional to faceplate illumination. Its third field lag is comparable with the Saticon at the higher light levels of its operating range.

Dark current in the SIT is usually not objectionable as long as the target voltage is set within the manufacturer's recommended limits.

One drawback with the SIT is that its faceplate exposure must be controlled for long life. Thus operation time and illumination level should be carefully controlled.

The SNR of the SIT is proportional to light level. Hence it is desirable to operate it with as high a faceplate illumination as is practical.

SIT faceplate overloads can cause picture blooming in spite of the fact that reduced-blooming SIT tubes are now available. In view of the fact that the life of the SIT is affected by scene illumination as well, extreme care should be used in the application of this device.

Intensified Silicon Intensified Target (ISIT) - The ISIT tube is essentially the same as a SIT, the only difference being the use of a double intensifier. This means that two intensifiers are stacked in series to yield a gain of about 2000 over a standard vidicon. Typical sensitivity of an ISIT tube is about 1×10^{-6} ft-candles faceplate illumination. However, there are some inherent disadvantages in using the ISIT system. Voltages of 20 kV must be used giving a lower reliability factor when compared to the single intensifier type (SIT). Also, noise level in the ISIT can become objectionable resulting in a highly grained picture presentation, and then a loss of resolution at the bandwidth of the random noise present.

Isocon - Since its introduction by RCA in 1947, the image isocon has drifted along more or less as a technological museum piece until a few years ago. In recent years RCA has built a practical version of this tube which has made it one of the most sensitive pickup tubes available for a TV camera.

Advantages of the isocon are:

1) Sensitivity - it provides pictures having a reasonable signal-to-noise ratio down to 2×10^{-2} ft-candles faceplate illumination
2) Resolution - 1000 TV lines limiting

3) SNR - reasonable, although not the best

4) Lag - comparable with the PbO tube

5) Signal Uniformity - excellent compared to other image pickup tubes

Self-Scanned Solid State Image Sensors - During the past 15 years, even though beam-scanned image tubes have been investigated and improved continuously, a parallel effort has been aimed at developing self-scanned solid-state image sensors as substitutes. Reductions in size, cost, and complexity were the immediate objectives, but the possibilities for improved performance and for new applications of TV have caused much interest. Recent advances in charge-coupled and charge-injection devices have proven that solid-state sensors will soon play a significant role in this field. However, the most advanced solid-state sensors developed to date do not match the best camera tubes in sensitivity or resolution. Further improvements in sensors will require a sustained effort in both sensor design and silicon technology.

Solid state cameras suitable for standard television are now available. RCA Solid State Division has a camera which uses their 512 by 320 element charge-coupled-device (CCD) sensor. It provides picture quality comparable to that of the 2/3 in. vidicon with the advantages of small size, precise image geometry, freedom from lag and microphonics, and resistance to image burn. The next largest commercial sensor, produced by General Electric Co., is a 244 by 188 element charge-injection-device (CID) sensor with two closecoupled MOS capacitors at each element. This type of sensor has X-Y address strips and peripheral digital shift registers for scanning.

Small 100 by 100 element sensors with photoelements interleaved between non-illuminated CCD registers are being marketed for surveillance purposes. Still smaller XY photodiode arrays with 50 by 50 elements and many types of single-line sensors are being

sold for such applications as process control and character recognition devices. There can be no doubt that solid-state scanning, either by means of X-Y address strips or by internal charge transfer, can provide a useful tool for image sensing.

5.1.1.7 Applications

CMS's can be used to provide realistic detail and a motion-perspective three-dimensional effect if used as image generators for the simulation of sensors which have pictorial displays - i.e., TV and infrared sensors. Current probe designs provide adequate resolution for simulating the widest FOV's - e.g., the 20° by 15° FOV of LLLTV sensor or the 16° by 12° FOV of FLIR.

The very narrow FOV's of IRST (0.1° by 0.1°) or high-resolution TV (as narrow as 0.66° by 0.5°) would require the design of large aperture objectives, which could be mated with the rear optical sections of existing probes, to make the diffraction limit of the probe compatible with finer angular resolution associated with the narrow fields of view. The use of a larger aperture would preclude use at eyeheights of under 2.5 mm, which are possible with present probes, for two reasons - mechanical interference of the probe with the model, and the increased depth of focus problems which accompany larger apertures. However, it can reasonably be assumed that the narrower FOV's would only be used for higher altitude flight. The current probes provide an 8 ft scale eyeheight at 1000:1 scale, which is required for helicopter simulation. In simulating close-support fighter craft, if a 200 ft minimum eyeheight is assumed, then there is no problem using a probe designed with, for example, a 1 cm pupil instead of a 0.8 mm pupil.

The pitch capability of existing single-reflection probe designs (+25°, -40°) covers the pitch requirements of FLIR and high-resolution TV, and comes within 5° of covering the require-

ments of all the sensors in Table 5.1.1.7-1 except IRST and day TV. These probes could be used for these sensors if useful simulation missions could be carried out without the full field of these sensors. It would not be a major design modification to increase the single-mirror pitch capability to (+30°, -45°).

The probes made in the past with double-prism mechanisms are not capable of the resolution of the current single mirror designs, but that is a happenstance not dictated by the choice of pitch mechanisms. A probe could be designed with a large entrance pupil and a double reflection pitch mechanism so that it could handle the pitch and angular resolution requirements of all sensors in Table 5.1.1.7-1. The minimum eyeheight would be much higher, since such a design would be bulky at the front end, but would be adequately low for any non-helicopter weapons delivery mission. Different FOV's could be implemented with variable magnification optics at the rear end of the probe.

A CMS would be much more appropriate for simulating slower aircraft, such as the A-10, than high speed aircraft such as the F-16. In the latter case, the aircraft would fly through the gaming area represented by a model of typical size and scale in less than a minute of elapsed time. A higher scale factor could be used if an extreme combination of low altitude and narrow FOV (which would aggravate the depth-of-focus problem) were not used. However, although such a model might be appropriate for some missions, it may not provide adequate depth of focus or model detail for other missions. A separate CMS system for a limited class of missions may not be practical from the standpoint of available space or capital cost. Alternatively, a CMS might be used to simulate sensors of a fast-flying aircraft only in the vicinity of a target area. Some other image source (e.g., computer generated) might cover a large gaming area, with a transition to the higher detail of the CMS taking place as the target area was entered. The problem is to make this transition inconspicuous, and this approach should not be considered unless a discontinuity at this transition could be tolerated.

Table 5.1.1.7-1 IMAGE PICKUP DEVICE MANUFACTURERS

AMPEREX ELECTRONICS CORP P.O. Box 278 Slatersville, RI 02876 401/762-3800	Plumbicon
EMR PHOTOELECTRIC Box 44 Princeton, NJ 08540 608/799-1000	Image Dissector
DUMONT/THOMSON-CSF 750 Bloomfield Ave. Clifton, NJ 07015 201/773-2000	Antimony Trisulfide Vidicon Silicon Diode Array Vidicon
FAIRCHILD CAMERA & INSTRUMENT CORP. Charge Coupled Devices 4001 Miranda Ave. Palo Alto, CA 94304 415/493-8001	CCD
GENCOM DIV/EMITRONICS INC. 80 Express St. Plainview, NY 11767 516/433-5900	Image Intensifier
GENERAL ELECTRIC COMPANY Tube Products Dept. Imaging and Display Products Electronics Park Syracuse, NY 13201 315/456-3231	FPS Type Vidicons - Antimony Trisulfide Silicon Diode Array Vidicon Charge Injection Device
GENERAL ELECTRODYNAMICS CORP. 4430 Forest Lane Garland, TX 75042 214/276-1161	Antimony Trisulfide Vidicon Silicon Diode Array Vidicon
HAMAMATSU CORP. 120 Wood Ave. Middlesex, NJ 08846 201/469-6640	SIT Vidicom X-Ray Vidicon UV - Vidicon Silicon Diode Array Vidicon IR - Vidicon
HUGHES AIRCRAFT CO/IPD 6855 El Camino Real Carlsbad, CA 92008 714/438-9191	CCD

Table 5.1.1.7-1 IMAGE PICKUP DEVICE MANUFACTURERS (Cont'd)

ITT ELECTRO-OPTICS 7635 Plantation Rd. Roanoke, VA 24019 703/563-0371	Image Intensifier
INTEGRATED PHOTOMATRIX INC. 1101 Bristol Rd. Mountainside, NJ 07092 201/223-7200	Self-Scan Photodiode Array
MULLARD LTD. Mullard House Torrington Place London WC1E 7HD England	Low-Light Level Vidicons Lead Oxide Camera Tube Image Intensifier
NI-TEC 7426 Linder Ave. Skokie, IL 60076 312/673-4770	Image Intensifier
OLD DELFT CORP. OF AMERICA 2735 Dorr Ave. Fairfax, VA 22030 703/573-7020	Image Intensifier
RCA CORP. Solid State Div. Electro-Optics and Devices Lancaster, PA 17604 717/397-7661	Antimony Trisulfide Vidicon Silicon Target Vidicon Saticon Isocon SIT - Vidicon Intensifier Vidicon Lead Oxide Vidicon Image Orthicon CCD Image Intensifier
RETICON CORP. 910 Benicia Ave. Sunnyvale, CA 94086 408/738-4266	Linear Area and Self-Scanned Photodiode Array
TELTRON INC. 2 Riga Lane Douglassville, PA 19518 215/582-2711	Antimony Trisulfide Vidicon Silicon Diode Array Vidicon CdS Vidicon CdSe Vidicon Pyroelectric Vidicon

Table 5.1.1.7-1 IMAGE PICKUP DEVICE MANUFACTURERS (Cont'd)

TOSHIBA AMERICA INC. OEM Division 280 Park Ave. New York, NY 10017 212/557-0406	Chalnicon (CdSe Target)
VARIAN LSE 601 California Ave. Palo Alto, CA 94304	Image Intensifier
VARO ELECTRON DEVICES 2203 Walnut St. Garland, TX 75040 214/272-3561	Image Intensifier
WESTINGHOUSE ELECTRONIC TUBES Westinghouse Circle Horseheads, NY 14845 607/796-3211	Antimony Trisulphide Vidicon Selenium Vidicon SEC Vidicon EBS Tube

5.1.2 Film Systems

Film-based systems have been used for simulation visual systems when the training task involves maneuvers for which there is a prescribed flight path. Visual simulation has been provided by film for some weapons delivery training, but the most satisfactory application of film-based systems has been in the use of simulators for take off and landing practice.

There are many advantages of using film as a medium. In general films have good resolution characteristics, are relatively inexpensive, are easily copied and stored, and allow a wide range of interchangeable scenarios to be used. The major disadvantage is that the task of acquiring the film scenarios is by no means easy. Two major approaches have been used: that of real-world filming which imposes problems of weather delays, camera vehicle stability, and flight profile control and operational limitations; and models which tend to limit the inherent scenario flexibility and realism.

Film has found a relatively wide application in part task trainers, but the only major use in a full flight simulation role was in the Singer-Link Variable Anamorphic Motion Picture (VAMP) systems which were used by commercial airlines in between 1970 and 1978 (see Figure 5.1.2-1).

In the VAMP system, for example, a motion picture camera is flown by helicopter down the nominal glideslope of an approach and landing sequence to film the scenario. The field of view in each frame is larger than that which is to be displayed in the simulator, in both horizontal and vertical directions. Differences of the simulated flight attitude from the nominal attitude are accommodated by the optical equivalent of shifting the film so as to change the portion of the frame which is projected into the limited display field of view. Deviation of the simulated flight path

to the right or left of the filmed flight path is simulated by optical transformations which "shear" the picture, making the rectangular areas on the film appear as parallelograms. This turns out to be a close approximation of the altered perspective of a horizontal plane surface (such as a runway) when viewed from the displaced eyepoint. Vertical relief does not fare so well -- telephone poles and the edges of buildings appear to lean as this "shearing" distortion is applied. The slope of the lean is the ratio of the lateral deviation to the height of the simulated eyepoint. Thus, while the lean angles would probably not be noticeable for high-altitude flight, this is certainly not true in the case of a landing approach. The system is made to work well for take-off and landing simulation by carefully selecting the runways to be filmed so that vertical objects can be excluded from the field of view. Vertical displacement from the nominal flight path is simulated by "stretching" the picture in the vertical direction (to simulate a higher altitude) or "compressing" it (for low altitude), again by optical techniques. This is also realistic for a horizontal plane, but causes some anomalous effects on vertical objects. For example, if the filming path passed over a

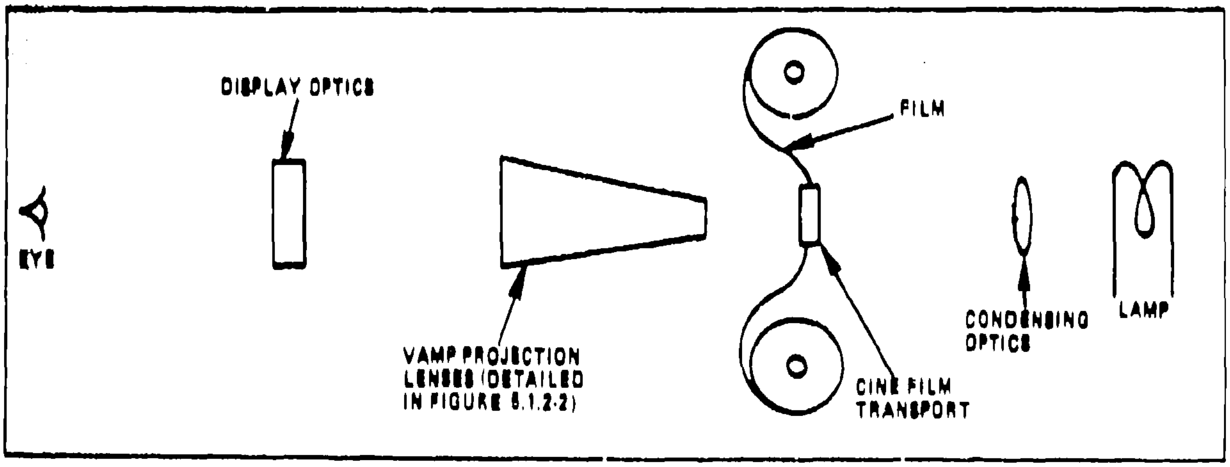

Figure 5.1.2-1 VAMP SYSTEM BLOCK DIAGRAM

mountain, a simulator pilot could not fly into the mountain no matter how low he flew, because the height of the mountain would shrink in proportion to the pilot's height above the horizontal plane assumed to represent the terrain.

The optical corrections are accomplished through the use of a zoom lens and two anamorphic lenses (see Figures 5.1.2-1 and 5.1.2-2). An anamorphic lens magnifies a picture differently in each of two different directions. By rotating the two anamorphs about the system axis relative to each other, the net anamorphic strength can be varied, and by rotating the pair as a group, the orientation of the anamorphic "stretch" is varied.

The limits of the deviation of the simulated flight path from the filmed flight path are determined by the excess field of view on the film, the strength of the anamorphs, the zoom lens ratio, and the amount of resolution degradation that can be tolerated.

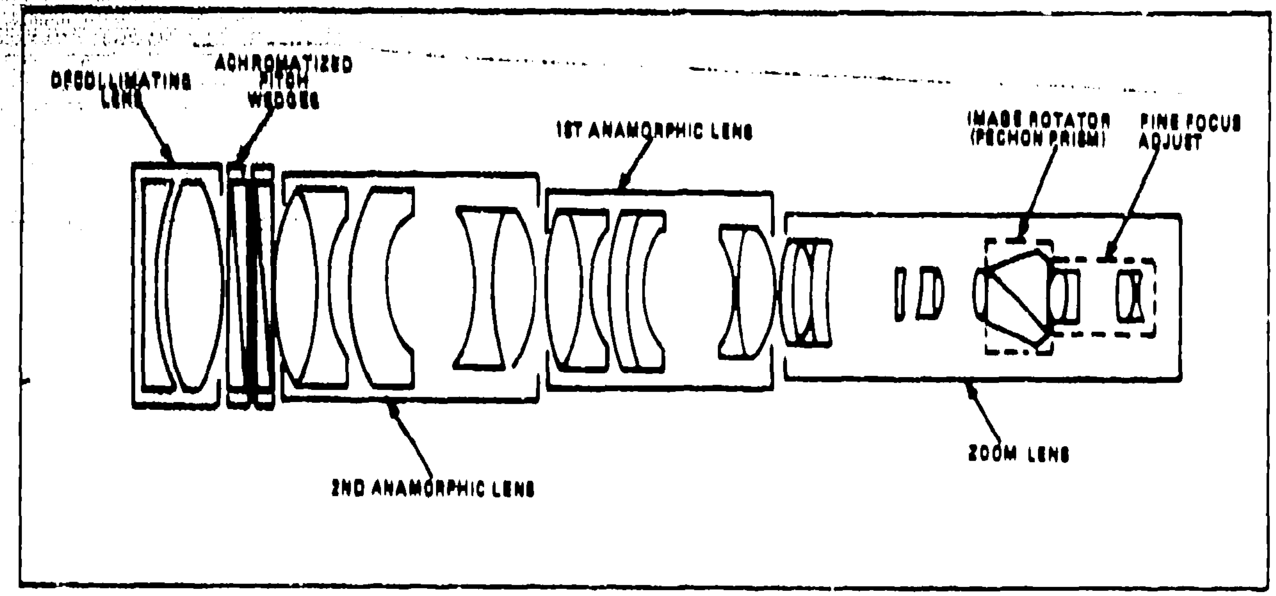

Figure 5.1.2-2 VAMP PROJECTION LENS

Figure 5.1.2-3 shows the maneuvering envelope for VAMP systems with 2.0 and 2.8 power anamorphs. Note that the allowed deviations are proportional to the filmed height above ground, and are given in units of this height.

The advantages of the use of film are the high detail density and textural information which it provides. Texture cues appear to be required for many piloting tasks and are processed by the trainee in ways that are not well understood. Hence, the surest way to guarantee adequacy of the visual simulation is to provide this sort of detail.

The VAMP system, however, suffers from the same problem that limits all systems based on film or tape: deviations from the nominal flight path can only be well simulated when all vertical objects are excluded from the scene. This is a necessary consequence of the attempt to represent a three-dimensional world on a two-dimensional medium. The exclusion of vertical objects may be more difficult and less natural in a weapons delivery mission than in a landing practice mission. In fact, the restriction to a narrow corridor about a filming path may be inappropriate for sensor simulation.

Link has developed another film-based system which is related to VAMP -- SCAMP or Scanned Motion Picture. This system is in effect an electronic analog of the VAMP. The information on the film is converted to a TV image by a flying-spot scanner (FSS), and is then displayed on a CRT display (see Figure 5.1.2-4). In the FSS, a spot of light imaged on the film is made to move in a raster pattern over the film frame being used at the moment. When no distortions are required to simulate deviations of the simulated eyepoint from the filming path, this raster is geometrically similar to (and synchronized with) the raster on the display CRT. The source of the spot which scans the film is also a CRT. The light from the image generation CRT is imaged onto the film frame

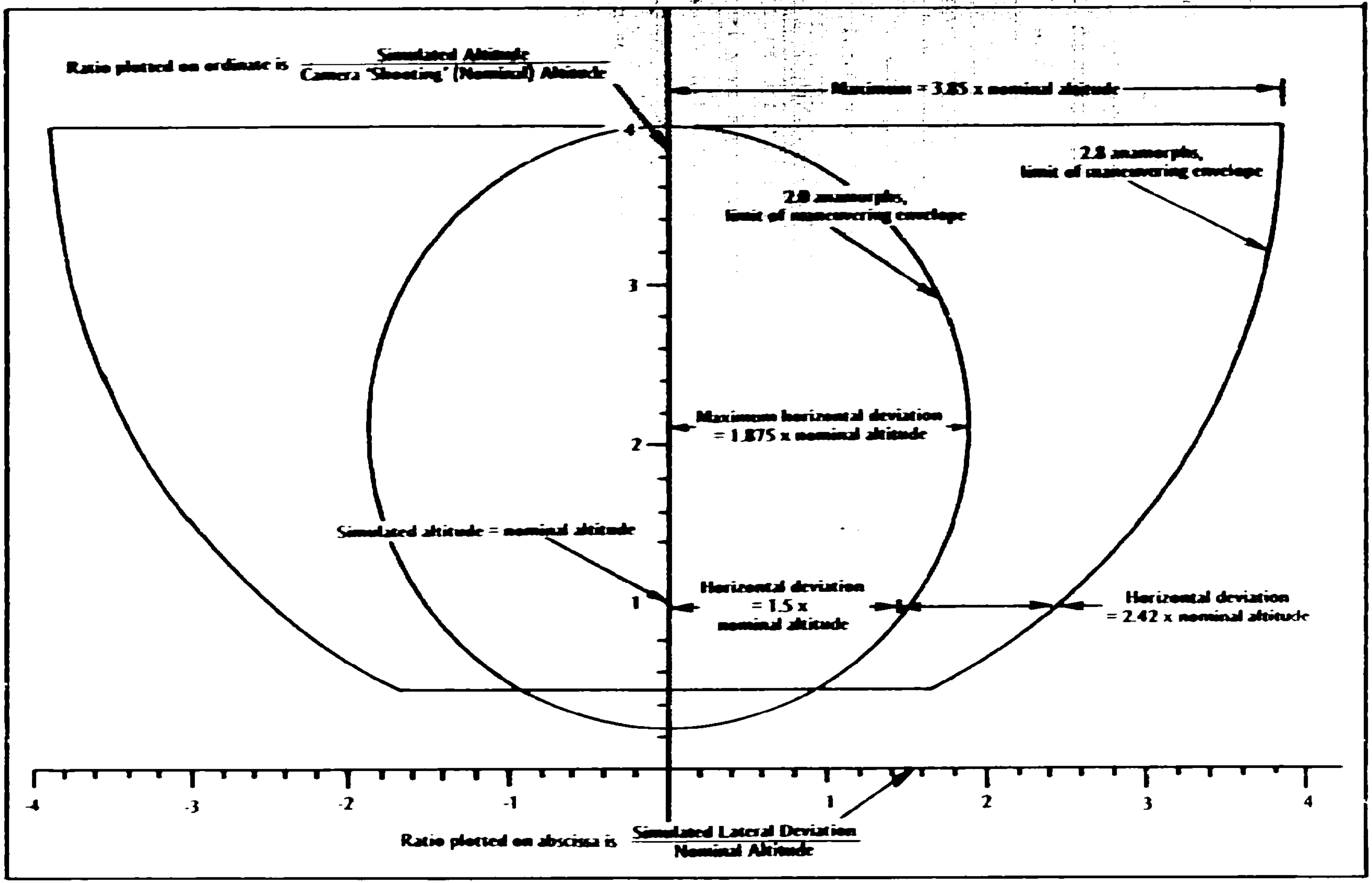

Figure 5.1.2-3 RATIO OF SIMULATED AIRCRAFT LATERAL DEVIATION TO CAMERA SHOOTING ALTITUDE

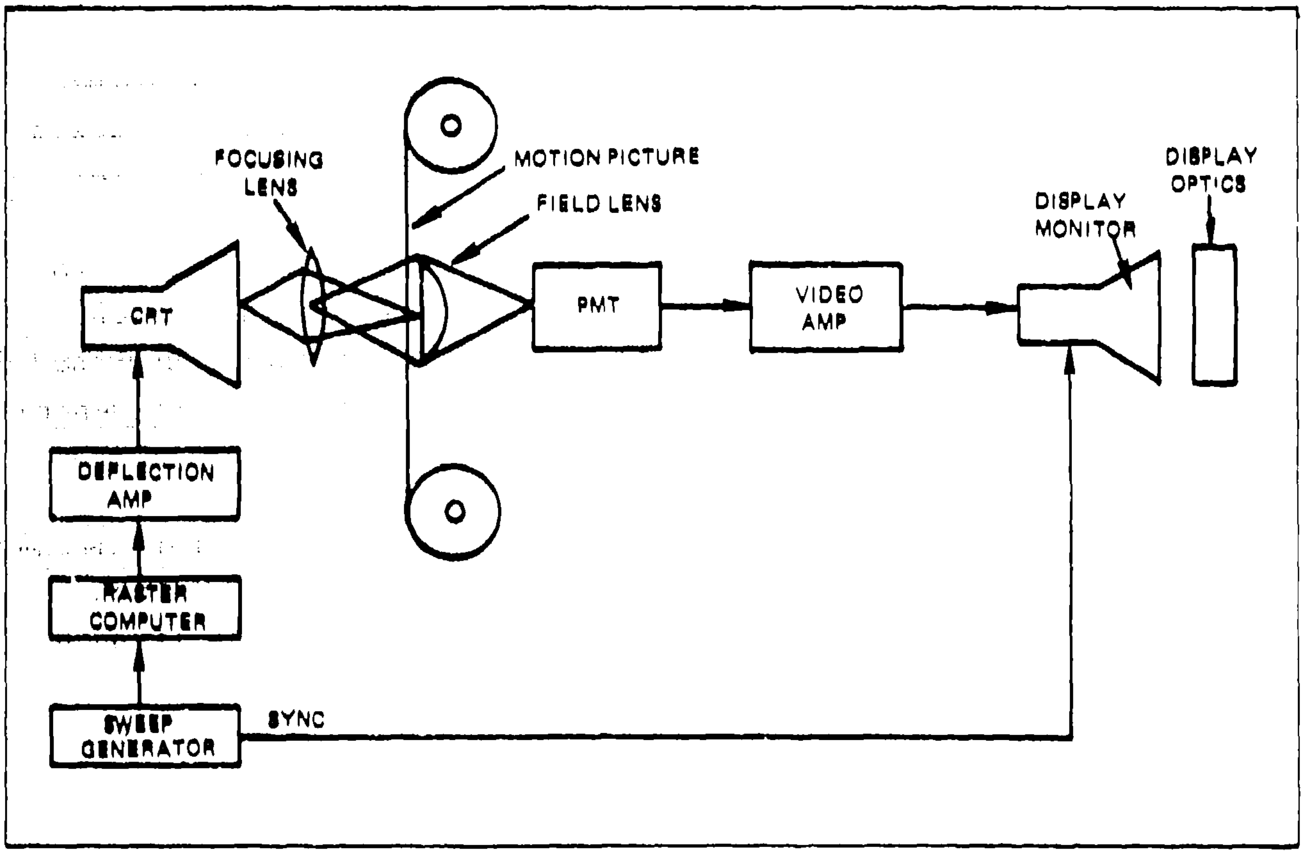

Figure 5.1.2-4 SCAMP SYSTEM BLOCK DIAGRAM

and, after passing through the film (which modulates the intensity of the light) is collected by a photo-multiplier tube (PMT). If the output of the PMT is used as the video signal and sent to the display monitor, the picture on the display CRT duplicates the picture on the film. Color video is provided by dividing the light transmitted by the film between three PMT's, each of which is restricted by a color filter to respond only to red, green, or blue light.

The distortions which VAMP performs optically are performed electronically by SCAMP. If the two rasters (on the image generation and image display CRT's) do not match, the result will be that the image on the display CRT will be a distortion of the image on the film. The required disparity of the two rasters to produce the distortions which will simulate eyepoint deviations from the filming path are accomplished by electronically shaping the waveforms which drive the deflection coils of the image generation CRT.

One advantage of this system is that the film transport mechanism is much simpler than that in the VAMP since intermittent "pull down" is not used. The film is moved continuously through the scanning aperture, with the FSS raster being displaced to track the film. Indexing to a new film frame is achieved during the TV vertical retrace period. Correlation between the scanning raster and film frame is achieved using fiducials on the edge of each frame. Although the perspective transformations can be exact for the horizontal plane (instead of approximate, as in VAMP), the same anomalies occur if there are large vertical objects in the scene.

Link has also patented (#3,832,046) a panoramic film projector which performs VAMP-like transformations on a 360° (horizontal) by 60° (vertical) panoramic picture as it is projected. In addition to overcoming the field-of-view restrictions of the VAMP,

this system provides for 350° variation of heading. However, in translation of the simulated eyepoint from the nominal eyepoint, the perspective transformations have the same undesirable effects on vertical objects as they do in the VAMP system, with an additional problem: the 360° field of view makes it far more difficult to exclude vertical objects from the film. This system is fairly complex mechanically and optically and has never been developed, since customer interest has not been sufficient to support the large development costs.

Systems with the capabilities of VAMP or SCAMP could be based on video tape rather than film. Although such systems are not available as integrated, off-the-shelf packages, the component technologies upon which such a system would be based have been within the state of the art for some time. In such a system there would be a recorded video frame on the tape corresponding to each frame in the movie film of VAMP or SCAMP. The distortions required to simulate deviations of the eyepoint from the points from which the scene was recorded would be accomplished by scan conversion. In an analog scan converter, the video is displayed on a CRT which is coupled to a TV image tube, which converts the picture back to video form. If the CRT and camera tube rasters do not track each other, the desired distortion can be introduced. DSC accomplishes the same thing by reading the video level of each pixel of the video frame into a separate memory location in a high-speed buffer, and can introduce a desired distortion by reading the video out in a different order and/or time schedule than that by which it was read in.

A particular weakness of such a system compared to SCAMP would be apparent when simulating a very narrow FOV that can be moved about inside a larger field. With high resolution film, SCAMP could scan a small portion of the cine frame, and the resolution would essentially be TV limited by the display raster (up to a point, of course, for very small FOV's, the film and the

scanning spot size would have an influence). However, when a subset of a video tape frame is displayed, information and resolution is immediately thrown away as soon as the displayed FOV is smaller than the recorded FOV.

All of the film or tape systems discussed in this section record a series of images from eyepoints along a predetermined path. However, some missions are difficult to simulate in this way even though the nominal flight path is predetermined. Link's experience with VAMP in simulating cross-country missions is an example. In these missions there were a number of course changes, and the pilot or navigator was provided directions for following the prescribed course. However, the maneuvering corridor was narrow, and if the course change was not done at precisely the right point, the picture was lost (i.e., the screen went black). Of course, the lack of a visual display made it difficult to get back on course. The constraints on the maneuvering envelope leading to this problem were not chiefly due to hardware limitations (although increased horizontal FOV would have been some help) but were more fundamental, having to do with the geometry of the perspective transformation. The practical limit of the width of the maneuvering corridor for a film or tape motion picture visual is of the order of the altitude of the nominal flight path (or much less, if vertical objects are present and one is required to limit the "lean" angles produced by the deliberate distortion). Thus, for use in simulating a weapons delivery mission, the mission path should either be very simple (e.g., straight approach to a target), at high altitude (giving a wide maneuvering corridor), or at low speed (e.g., helicopter NOE). At low speeds, the pilot has more time to correct his path before he gets out of the corridor.

There are other uses of film in addition to the motion picture approach. A collection of slides can be provided for use as high detail target insets. The slides could be accessed more easily if they were transcribed onto a video disk.

For the past ten years a number of laboratories have been developing video recording systems separate from videotape systems. These are known as videodisk systems. They use electromechanical, capacitive, magnetic and optical (using a laser beam) recording and playback techniques.

Once quick retrieval of snapshots is provided by videodisk, it becomes possible to construct a system which overcomes the restriction of the motion picture systems to eyepoints along a linear path. Pictures could be stored for eyepoints distributed at intervals all throughout the volume of a maneuvering space. A system would consist of a large number of stills, each of which would be divided into a series of sub-pictures and stored on video disk or tape. Each store picture would correspond to the resolvable picture elements of the frame to fit the bandwidth capability of the storage medium. The picture would be re-compared on a scan-converter tube, using the random-access capability of a disk to choose only the portion of the picture being viewed. The small FOV capability could now be configured to be a film limitation rather than a limitation of storage media on TV if the original photograph were divided into sufficient segments. A 70 mm by 70 mm picture contains over 4,000 picture elements in each direction, and if a standard 525-line disk or tape were used, the single picture would require over 60 television frames of storage.

In use, the picture retrieved would be "flown" through for a while, and not changed as is a movie picture. Each frame could be flown for a short while, until the next picture location is reached. Such a system would have the advantage of allowing much greater freedom of flight, since the disk would allow rapid random access between pictures which would alleviate one of the most serious faults of the VAMP or SCAMP approach.

Even so, even a multiple disk system would have only a limited data base, and while new data bases could be made, the

generation of a new film base is not a trivial task. A single disk would hold 900 pictures (based upon 60 television frames per picture).

This system would still suffer from the same distortion problems that limit low-altitude flight simulation, while adding the additional difficulty of creating a smooth flight profile when going from one picture to another. This would, of course, require the development of a large data storage and retrieval system. Although the required hardware components are within the state of the art, a large development effort is required to make this approach available. Such a system would bypass the limitations of a linear maneuvering corridor.

To summarize, motion picture film-based systems may be suitable for simulating some of the TV and IR sensors in selected missions. An FSS, as in SCAMP, is a convenient way of generating video for the displays. The preprogrammed nature of such simulation will cause the fewest problems in the case of high-altitude missions, and resolution will be the least problematical for the wider instantaneous fields of view. Some of the limitations of motion picture systems could be removed by a system based on video-disk, but such systems belong to the future, not the current state of the art.

5.1.3 Video Tape/Disk Systems

The first practical videotape recorder (VTR) was introduced in 1956 by the Ampex Corporation. It used 2-in. wide magnetic tape that ran at a speed of 15-in. per sec past a magnetic head which rotated at a high rate of speed. The scanning of the tape was done in a transverse manner compared to the present day technique of helical scan. It was capable of a horizontal resolution of 320 lines, had a video bandwidth of 4 MHz, and an SNR of 30 dB or more.

Current VTR's have one drawback in that their performance improvement has, over the years, been concentrated primarily at meeting the needs of TV broadcasters, where the horizontal resolution requirements are approximately 300 lines, scan line rates are 625 lines per frame maximum, and video bandwidth requirements are approximately 4.0 MHz. In simulation work, horizontal resolution is typically 1000 lines, scan line rate is 1023 lines per frame, and video bandwidth, 30 MHz. However, the International Video Corporation (IVC) recently developed a new wideband monochrome VTR which closely meets the needs of simulation. The IVC Model 1010 VTR is capable of recording a full 10 MHz video bandwidth with an SNR of 43 dB at scan line rates up to and including 1225 lines per frame. It utilizes 1-in. helical scan videotape and provides one hour of video record time. Figures 5.1.3-1 and 5.1.3-2 illustrate the record and playback modes of a VTR which might be used in a sensor display system. Recording may be done from either an analog image generator or a digital image generator.

This VTR has features of stop motion viewing and continuous variable slow motion, and can be remotely controlled in all of its operating modes. This makes it ideal for a sensor simulation task where image display can be accomplished under computer control.

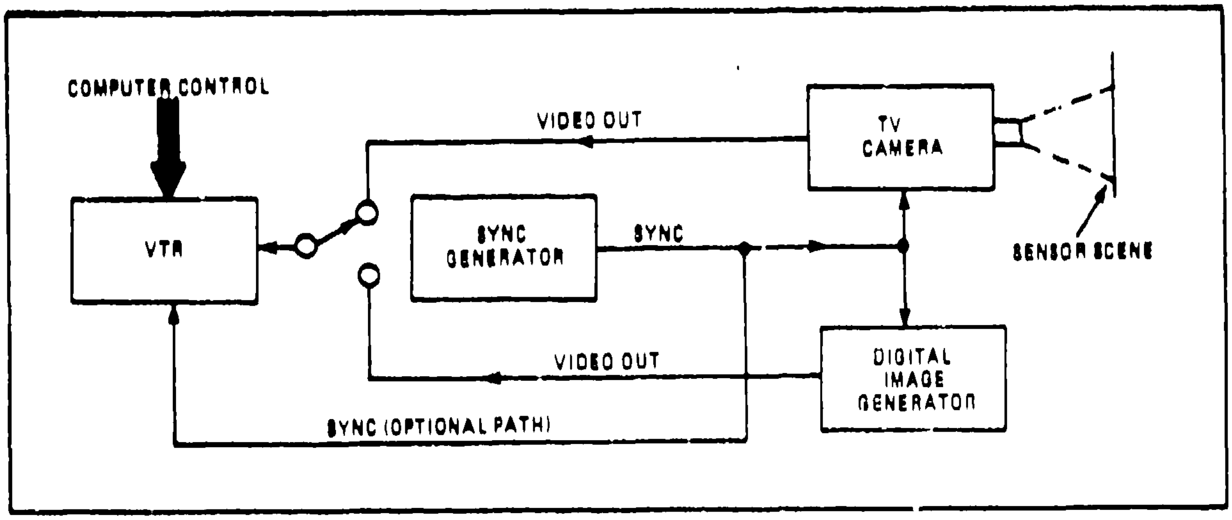

Figure 5.1.3-1 RECORD MODE

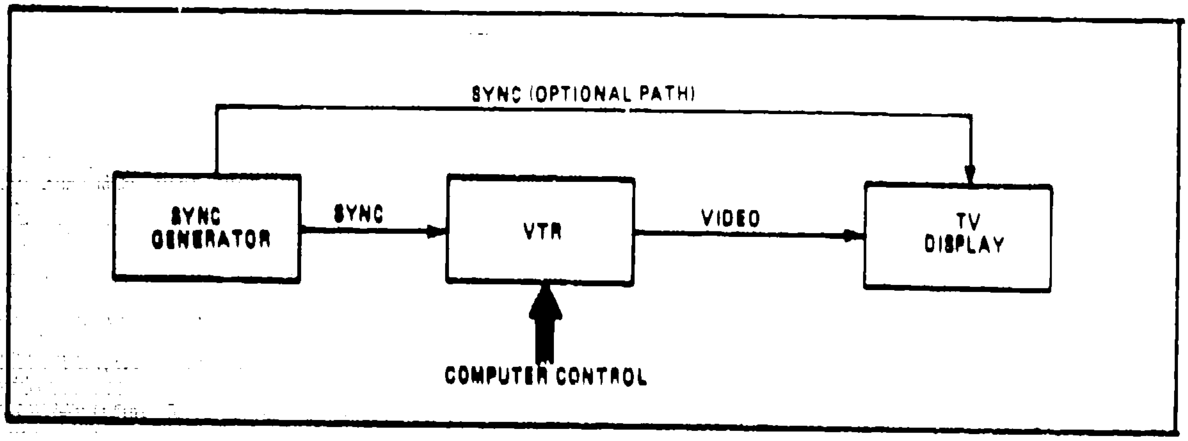

Figure 5.1.3-2 PLAYBACK MODE

It should be noted that color VTR's are still limited to a 525/625 line scan rate, a 4.2 MHz bandwidth, and a 45 dB SNR. Higher color resolution performance might be achieved by using three of the IVC Model 1010 VTR's very precisely tracked together but the cost effectiveness of this approach is doubtful.

A popular type of VTR in widespread use today uses 3/4-in. videotape in a cassette format (known as the 3/4-in. U-Matic cassette). This eliminates the problems of tape handling by the operator but its performance to date is limited to the commercial broadcast standards of 525 or 625 lines per frame, 320 lines of horizontal resolution (monochrome), 240 lines of horizontal resolution (color), and an SNR of 45 dB (monochrome).

While the last several years have seen the introduction of a great deal of digital TV signal processing equipment, videotape recorders have remained analog. In a digital video recorder, the analog input signal is source coded to digital form by an analog-to-digital (A/D) converter, and then channel coded and recorded. During playback, the digital signal is channel decoded back into digital source code, and then further decoded to analog form with a digital-to-analog (D/A) converter. For a digital recorder, the SNR of the playback video is essentially limited by the quantiza-

tion noise of the A/D and D/A conversions rather than by the noise generated by the recording media and electronics, as is the case with conventional analog video recorders. Furthermore, deleterious effects such as moire, residual time-base errors, and chroma banding are non-existent. In recent years, VTR industry leaders such as Ampex, Sony, and Bosch-Fernseh have demonstrated prototype digital VTR's. While it is apparent that the digital VTR is the way of the future, there are still many problems to be solved before a practical commercially-available device is produced. These include the choice of video sampling rate, component versus composite encoding, error masking magnetic recording code, choice of scan format (i.e., longitudinal, transverse, or helical), and writing speed versus the number of parallel channels.

Videodisk systems are just beginning to become available on the market place but their performance capabilities are limited to that of commercial television. They may be computer-controlled, provide automatic random access to stored data, provide slow-motion, freeze-frame, or frame-by-frame viewing, have a range of forward-or-reverse speeds, may be programmed with interactive information, and may have recording capability of 60 minutes of color video per disk. These disk recording systems may be applied to a sensor display system in much the same manner as the VTR described previously. The main advantage of disk recording systems is their higher information packing density over tape. They do suffer from lower quality reproduction than tape recorded pictures and the fact that the ease of recording and playback leaves a lot to be desired. Master disks must be made on expensive machinery in centrally located plants.

5.1.4 Laser Scanner

The Laser Scanner Image Generator (LSIG) represents the state of the art in modelboard image generation. It overcomes the inherent limitations of vidicon-based CMS's and is ideally suited for

the sophisticated military training environment. The LSIG provides high resolution, high scene detail, full color images. It is of particular interest for the low altitude training requirements of rotary wing aircraft.

Figure 5.1.4-1 is an artist's concept of the LSIG. The system employs a multi-colored laser beam to scan a conventional high-detail modelboard. As the laser beam is scanned across the modelboard within the pilot's FOV, the reflected light from the model is detected by a bank of photomultiplier tubes. The detected signal is amplified to provide a full-color video input signal to a standard simulator display system which may be a CRT or a projector.

The laser beam originates at the laser table, as shown in the figure, and is transmitted along the gantry axis to the scanner assembly within the laser scanning head. The scanner generates a raster which is projected through the probe to the modelboard where it is reflected to the photomultiplier tubes. The video signal is generated through the summation of the outputs from all PMT's. The resulting image has the correct perspective and line of sight as seen from the exit pupil of the projection probe.

The laser table, as shown in the artist's conception, holds three lasers, the beam expanders, and the combining optics. The table provides an optically flat and stable mounting surface and with covers in place, provides a clean and thermally controlled environment. Four spectral lines of laser light are provided to produce excellent color fidelity. An argon laser provides the blue and green. The red line is generated by a krypton laser and the yellow line is derived through a tunable dye laser.

The laser scanning head contains the probe, the high-speed scanner, optics, and support equipment. The combined laser beam is routed along the gantry X, Y, and Z axis to the scanner. A

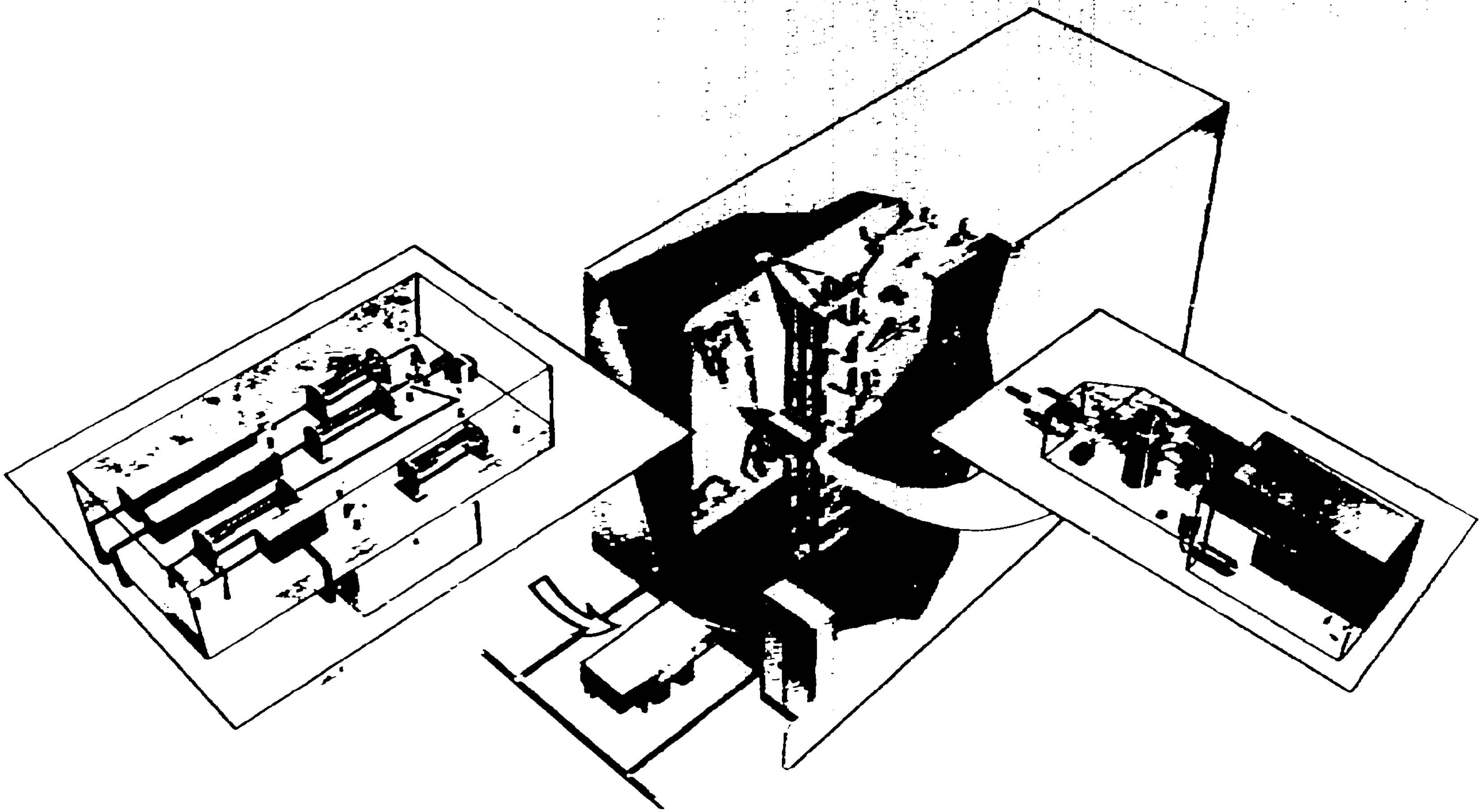

Figure 5.1.4-1 ARTIST'S CONCEPTION OF LASER SCANNER IMAGE GENERATOR

servo-controlled mirror system is used to correct for beam positioning errors. Line scan is provided in the high speed scanner through a rotating multifaced mirror polygon, and frame scan is provided by a galvanometer driven mirror. The resulting raster is projected through the optical probe into the model board. The probe, in turn, contains the necessary servo mechanisms to provide heading, pitch, and roll response as a function of aircraft position.

The laser light reflected from the model board falls onto the bank of PMT's that are arranged in triads, each PMT in the triad being mounted behind a red, green, or blue optical filter. The outputs of the triads are added together to produce a standard RGB video signal.

Additional PMT triads are located on the gantry and probe assemblies to compensate for the shadowing effect they create. Cultural and airfield lighting is simulated by fiberoptic collectors mounted through the modelboard and connected to a separate photodetector system. Control of lights is thus separate from the rest of the video scene, allowing increased realism in the simulation of tactical night and low visibility scenarios. Visibility, horizon and special effects are introduced in the video-processor as in conventional systems.

As with the high-resolution TV CMS the laser image generator modelboard is designed with rigorous adherence to correct scale factors, so trainees can properly judge altitude, altitude rates, slant ranges, closure rates, etc.

The latest high-fidelity modeling techniques produce exceedingly accurate detail, making the system especially well-suited for helicopter training including NOE operations below tree-top level.

A high scale factor, such as 1,000:1, expands the flying area of the system, increasing scene detail and allowing even individual trees to stand up to close inspection.

The major differences between the TV CMS and the LSIG are replacement of the television camera by the bank of light sensitive PMT's, and replacement of the model illumination light bank by the scanning laser beam. The elimination of the lamp bank reduces power consumption and provides a thermally stable environment for increased maintainability.

As shown in Table 5.1.4-1, the LSIG provides excellent performance. Since the PMT has no image lag, there is no dynamic loss of resolution. The high SNR results in a clean image with little or no background noise. Color registration is simple and stable since this is no longer dependent on deflection geometries and yoke characteristics. Finally, the laser beam makes maximum use of the projection aperture by filling it completely and thereby increasing resolution.

Table 5.1.4-1. LSIG PERFORMANCE SPECIFICATIONS

System resolution (limiting)	6.5 arc-min per line pair
SNR	46 dB
Gray scale	10 shades
Contrast ratio	15 to 1
System geometry	Within 0.5% for central circle picture height, within 1% elsewhere.
Minimum eye height	6.5 ft
Display FOV	60° diagonal per channel (48° horizontal by 36° vertical)
Display brightness	7 ft-lamberts
Display convergence	Within 0.1% for central circle of picture height; within 0.2% elsewhere.

LSIG represents a new technology. Demonstration systems exist within the simulation industry which have served to prove the basic concepts but no operational systems have been fielded to date.

The technology does offer certain advantages over more conventional camera model systems, but its application to FDL's sensor simulation is questionable. The advantages are in areas such as maintenance, dynamic lag, and cultural lighting. These items are more important for an operational training facility where long hours of constant use are required and especially for helicopter flight training where close approach, low speed, high scene detail, low dynamic lag, and color are of primary importance.

In simulating sensors, the laser systems are limited by the same laws of physics discussed in the sections on CMS's. The optical problems associated with probe design are equally serious and the limitations in gaming area and probe protection are not improved through the use of laser scanning technology.

Finally, since CMS's already exist at the FDL facility, it is questionable whether the acquisition costs of an LSIG could be justified considering its limited application in sensor simulation.

5.1.5 Digital Image Generation

5.1.5.1 General

Images generated for various sensors necessarily differ in the kind of parameters and level of scene detail required. The extent of these differences has been investigated in terms of the image generation requirements for each type of sensor system and by evaluation of the various sensor peculiarities. Some of the salient characteristics of FLR, FLIR, LLLTV, and visual images are discussed in the following paragraphs.

5.1.5.1.1 Comparison of Sensor Characteristics

An airborne radar (e.g., FLR) is an active device in which the displayed imagery results from reflection of transmitted pulses of very short wavelength originating from a transmitting antenna. After each pulse transmission, the antenna switches to a receiving mode and collects the reflected signal for amplification and CRT display along a radial sweep line. The positions and brightness of each point along this sweep are indicative of slant range and radar reflectivity, respectively, of objects encountered by the radar pulse. Horizontal scanning motion of the antenna beam provides a slowly refreshed FOV in front of the moving aircraft in the familiar sector scan format.

By contrast, IR, FLIR, LLLTV, and visual sensors are passive in nature and depend upon high resolution optical scanning of scene images. For CIG, each of these sensors can be considered a raster-pattern scanning system, differing only in spectral response, resolution, image format and display characteristics.

This comparison indicates that a sector scan image generation system for FLR differs in a rather fundamental way from those using the raster-type display. Not only does the slowly refreshed

display appear quite different, but the image processing and projection algorithms are also divergent. Display position for a given object is determined in the radar display by slant range from the antenna and azimuth bearing from aircraft heading. In the other sensor displays, a true visual perspective view is produced (although it may sometimes be modified for wide-angle viewing).

Another important difference is the effective range and resolution. As shown in Table 5.1.5.1.1-1, resolution for radar is an order of magnitude poorer than FLIR resolution, but range is much greater. This implies that many more objects will be visible in a radar scene but to a lower level of detail than for corresponding FLIR raster-scanned images. Radar wavelengths are relatively unaffected by weather, atmospheric effects and darkness, whereas visible and IR wavelengths are attenuated rather sharply by these conditions.

Table 5.1.5.1.1-1 USAGE AND PERFORMANCE CONTRASTS BETWEEN FLR AND RASTER-TYPE SENSORS

	FLR	FLIR, LLLTV, Visual
Area of interest	Unlimited	Unlimited
Effective resolution	Approximately 100 ft	Approximately 10 ft
Effective maximum altitude	70,000 ft+	40,000 ft (typical)
Effective slant range	200 nmi	7 nmi to 25 nmi

Resolution in the radar system is primarily determined by the angular width of the transmitted beam (azimuth beamwidth), typically about 2° and the pulse length of typically 0.5 μsec. For the passive sensors, resolution is limited by the size of the smallest solid angle which can be sampled by the scanner or resolved by the unaided human eye. A typical IR scanner can resolve about 3 mrad of arc which translates to about 6 ft at a 2,000-ft range.

5.1.5.1.2 Image Intensity and Color

The intensity of points in the CIG is also dependent largely on the type of sensor. Intensity in an FLR image is determined by the strength of the return from objects at equal bearing and range from the aircraft. This strength is determined in turn by object reflectivity at radar wavelengths, object aspect angle, antenna gain pattern, and weather and atmospheric effects. Of course, the settings of various operator controls also affect the intensity (e.g., antenna tilt, IF gain, etc.).

Dark areas of the radar image are due either to low reflectivity of objects present, such as water, which reflects the radar energy away from the antenna, or the absence of any reflecting object at that slant range position. The latter condition refers to occulted areas or areas shadowed due to terrain or cultural relief.

Several objects may appear at a coincident display position due to their equal slant range distance from the antenna; for example, in rapidly rising terrain.

The beamwidth (typically 2°) and pulse length (typically 0.5 usec of the radar pulse also contribute errors which smear or blend together objects with small angular or slant range separation, respectively.

Raster-scanning image sensors in the visible spectrum (including LLLTV) have a rather more complex intensity function. The scene intensity varies as a function of slant range, incident light, time of day, sun (or other illumination source) position relative to sensor, object aspect, clouds, weather, object color, and reflectivity or albedo. For visual sensors, such as out-of-the-window displays, the objects must also be described in terms of primary color intensity for complete sensor image generation. A few objects in the daylight scene may be radiation sources of visible light (e.g., beacons, runway strobes). At night, the number of light sources can be enormous.

IR sensors are dependent primarily on radiated IR wavelength energy rather than reflected energy for the intensification of image points. Thus, it is usual for bright image areas to represent hot objects (e.g., cultural areas heated by the sun) and darker areas to represent cooler objects (such as water, vegetation, and shaded areas). The temperature of objects is obviously dependent on recent meteorological history and time of day, as well as emissivity and temperature time constants (heating and cooling) of various surface materials. Color may also be used in IR imagery but is only indicative of various IR intensities.

Any of the sensor types may exhibit other peculiarities due to particular transfer functions, operating modes, or image enhancement features. An example of these peculiarities is blooming and smearing due to image intensification in LLLTV systems.

5.1.5.2 Real-Time CIG

There are an almost infinite number of unique visual/sensor effects which are worthy of detailed study. To a great extent many of these are independent of the method of image generation and are best left to a psychophysical study of visual simulation systems (see Kraft et al, 1980).

This study concentrated on the currently available CIG systems and on the CIG systems that are under consideration by the military and manufacturers. The image processors (both visual and IR sensor) will be discussed to illustrate what processing approach was taken by manufacturers, the reasons for those decisions, and why they are quite similar. Also, the basic limitations of current CIG systems will be discussed, along with the possible modifications, additions, and redesigns that appear necessary to minimize the present objections to CIG. Lastly, the implementation of a CGI system to generate the IR sensor scene including the generation of the anomalies inherent in IR sensor imagery will be discussed. This will cover the choice of image processor, the modifications to the data base, and the post-processing necessary for the unusual special effects.

The data base generation systems have become increasingly important to the overall simulator acceptance, in terms of both data base cost and scene design. For this reason the methodology for scene data entry and its ramifications will be discussed with regard to how the content influences the image processor. A discussion of data base considerations appears in Section 5.1.5.3.

5.1.5.2.1 <u>General Description</u>

It appears that all sophisticated real-time CIG that have been delivered to the various users and those CIG presently under contract function in much the same way. These real-time CIG normally generate images at 30 frames per sec. Because of this high frame rate, no general-purpose computer alone can do the job. Consequently, a real-time CIG system usually consists of a general-purpose minicomputer and a large, special-purpose pipeline processor.

Depending upon the processing algorithms used, the architecture of the special-purpose image processor varies little among

different real-time CIG systems. Most processors can be partitioned into three subsystems, as depicted in Figure 5.1.5.2.1-1. The major function of the frame rate processor is to obtain a description of the silhouettes of potentially visible objects in terms of the two-dimensional screen (image plane) coordinates given their three-dimensional description in the environment coordinate system. When objects are modelled by planar surfaces, the silhouette description of each potentially visible planar surface is usually in terms of potentially visible planar surface edges defining its boundaries. Each of these edges is characterised by edge parameters which define where the edge starts, ends, its slope and the shading information of the surface with which the edge is associated. The scanline rate processor takes the description of these silhouettes (planar surface-edges in cases where the objects are modeled by planar surfaces) from the frame rate processor and generates for each scanline their visible intersections (ordered from left to right, if the scan direction is from left to right). Finally, the picture element rate processor takes the visible intersections together with shading information to their right and generates the shade for every picture element on the scanline.

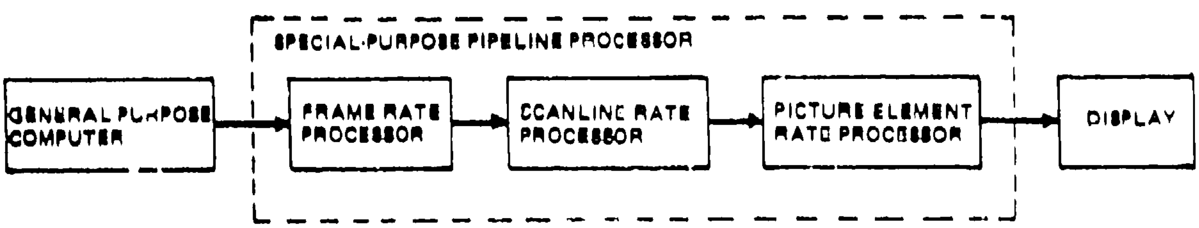

FIGURE 5.1.5.2.1-1 ARCHITECTURE OF THE SPECIAL PURPOSE PROCESSOR OF A REAL-TIME CIG SYSTEM

5.1.5.2.2 Limitations

Since all real-time day-night CIG systems operate at TV frame rates[1] the amount of scene detail is limited to the number of scene elements (edges, polygons, etc.) that can be computer-processed in 1/30th of a second. All manufacturers made the many trade-offs between cost, scene detail, and user application slightly different and, hence, the CIG specifications from each manufacturer are different. The various manufacturers have delivered CIG systems that process from 2,000 scene edges (500 polygons) to 8,000 scene edges (2,000 polygons) with systems processing up to 30,000 edges said to be under development. There are other parameters that vary slightly from manufacturer to manufacturer such as levels of occulting, scanline crossings, gaming area, etc. However, the interaction of each of these parameters makes it extremely difficult to rank the various CIG system objectively.

The most complex CIG scene that can be generated by a CIG is, at best, an abstraction of the real world. More hardware and faster processors can produce more complex scenes, but no matter how many edges are employed, the scene does not contain nearly the amount of detail that is apparent on a CMS.

[1]Actually, the display frame rate need only be greater than 24 frames per sec so that the image would not appear to flicker. The use of 30 frames per sec is dictated soley for purposes of electronics simplicity.

For practical reasons of cost and complexity the image processor designs have been limited to using planar descriptions of the desired scene.[2] A further simplification is that a single color intensity is calculated for each polygon. These two simplifications (planar surfaces, single color) result in a displayed scene which is somewhat unnatural, particularly when attempting to portray terrain and vegetation since little faceting occurs naturally. Man-made (cultural) objects, on the other hand, are composed of planar surfaces or are relatively simple geometric figures and thus appear realistic in CIG.

This problem is accentuated when the mission scenario requires low-level or NOE flight. In these cases the planar surfaces must be made large so that the image processor can produce a scene over a large field of view with a reasonable visibility range. When the eye approaches these large detailed surfaces there is little other scene data available in the immediate foreground to aid positioning of the aircraft. Real-time data base generation and the addition of texture on the surfaces may minimize this problem. Both techniques are being developed and will be discussed separately.

It should be pointed out that this problem is not entirely eliminated by the many scene-levelling techniques that are in use or under development. These systems usually require that an object be assigned a location in the data base and given an object priority or, at a minimum, share a priority with a limited set of objects. In those systems that do not use separating plane trees the priority problem does not exist, but the basic scene edge capability is much more limited to begin with.

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[2]Smoothing algorithms are employed by all the CGI manufacturers to extrapolate the shading of objects to produce a rounding effect. These provide a great improvement in realism but some faceting still remains and the algorithms do nothing to reduce the noticeable straight-line segment silhouette.

5.1.5.2.3 Other Computational Approaches

Various researchers have studied the computer rendition of parametrically defined surfaces (especially bicubic patches) for curvilinear object simulation (see Catmull, 1974, Blinn, 1978, Whitted, 1978, Lane et al, 1980, Clark, 1979, and Yan, 1980). Curvilinear objects generated with these surfaces are free of artifacts associated with objects modeled with planar polygons. Unfortunately, it is much more difficult to obtain the silhouettes of objects and to perform intensity computation as well as texture modulation within the silhouettes of objects on objects modeled with parametrically defined surfaces than objects modeled with planar polygons.

Consequently, it does not appear that a cost-effective, real-time implementation of rendition of objects modeled with parametrically defined surfaces is feasible in the near future.

5.1.5.2.4 New Designs and Architecture

The capability of present CIG architectures has reached a limit, due to system complexity, and new DIG designs will eventually shift to a different architecture. A similar complexity limit has appeared in data bases and, consequently, data base construction techniques will change as well.

The current hardware architecture uses a long, single pipeline to accomplish the image generation. This type of architecture requires new pipeline segments to add new features. But the system maintainability problems will increase for systems larger than the present CIG's. The alternative is to use an architecture with many small processors operating in parallel. Such architecture will be much easier to design and maintain, and will permit more widespread use of large scales of integration.

In addition to the change towards parallelism, future systems will incorporate a full frame buffer. This will eliminate scan-line-related restrictions such as the limit on the number of scan-line intersections. The processing restrictions will be on a frame basis rather than a line basis, which will be a substantial improvement from the user's viewpoint. The frame buffer also simplifies the implementation of many features, including advanced features such as translucent clouds.

For the data bases, the trend will be towards the greater use of pseudorandom generation techniques, so that much of the data base detail will be generated as required in near real time. The detail would fill in outlines generated conventionally. This will reduce the expense of data base generation and solve the problem of accessing the data bases fast enough from mass storage (this is discussed further in Section 5.1.5.2.7).

Approaches to parallel system architectures and pseudorandom system generation are described in the SIGGRAPH '80 proceedings. However, it is difficult to predict when the benefits of research along these lines will be available in product form. A parallel architecture frame-buffered system will certainly be proposed within two years. The improvements in data base generation will probably not come along as fast, and are perhaps four to five years away.

The hardware architectural changes are inevitable. Advances in semi-conductor technology are occurring so rapidly that within a few years competition will force the manufacturers to construct such a system. The data base technology, however, is software, and there is no great push from technological innovations in software. Consequently, the changes in data base techniques are more speculative.

5.1.5.2.5 Modified and Hybrid Systems

Recently some modifications to the basic CIG structure have been made. One of these modifications consists of using the image processor in a dual capacity, partly as a night-only (vector display) and partly as a day-night system (raster display). This is implemented by using some of the available frame time to display light sources in a calligraphic mode. Although the scene is presented on a shadow mask CRT rather than the normal beam penetration tube CRT used for night-only systems, the images of the lights are far better than the images obtainable on day-night CIG systems. In turn some compromise has to be made in the day scene because of the frame time being used for the calligraphic mode. The number of frames displayed per second is reduced causing the scene to flicker even when the display brightness and contrast are reduced to minimize this effect. Other compromises in scene processing may also be required.

A second class of simple CIG systems has also been introduced and is finding some limited application in simulation where the eyepoint, for example, has a very limited range of motion. In these cases the visual system background scene is imaged from the real-world scene and stored on a videodisk. In operation the background scene is retrieved from disk and projected onto a screen while only the limited detail targets are computed and overlayed over the background. In addition, little or no occulting is computed. The system is inexpensive but obviously has the disturbing occulting and insetting problems. There are a number of different versions of this type of system, particularly in the area of air target simulation.

5.1.5.2.6 Texture

As stated previously, the planar surface image as currently available is inadequate for some applications. This is particu-

larly true for full mission simulation where the visual system must provide adequate cues for low-level or NOE flight. Real-world confusion must be incorporated in the simulated image presented to the pilot (see Figure 5.1.5.2.6-1). Planar surfaces are too explicit to represent nature's subtlety. To solve these problems and provide faithful real-world training cues we must find an alternative data base representation completely independent of edges. Such a representation is provided by texturing.

Texturing has three basic qualities that make it ideal for modeling real-world features. First, it can be spatially unlimited. A texture function can be defined for the entire scene space, allowing large areas to be modeled by an extremely small data base. Second, it can provide the necessary complexity and irregularity by generating seemingly random patches and blobs. Third, it can mimic nature's subtlety, deliberately avoiding specific boundaries by blending shading from patch to patch.

Texturing is not a new concept; it has been discussed for years. But four basic problems have delayed effective implementation: choosing a texture model, correlating the model with real-world features, assuring perspective validity, and implementing texture generation at real-time display rates.

Three different generic texture models have been suggested. The first uses stored digitized images of real-world features. The problems of data base management and perspective transformation make this approach acceptable only for limited simulation scenarios. At the other end of the spectrum, the second technique involves adding a random signal to the projected image of a scene. Such an approach simplifies high-speed implementation but sacrifices realism, perspective, validity, and even frame-to-frame consistency. Between these two extremes lies the third method of texturing, defining a mathematical function that will generate the desired pattern. Such a model can be defined by a

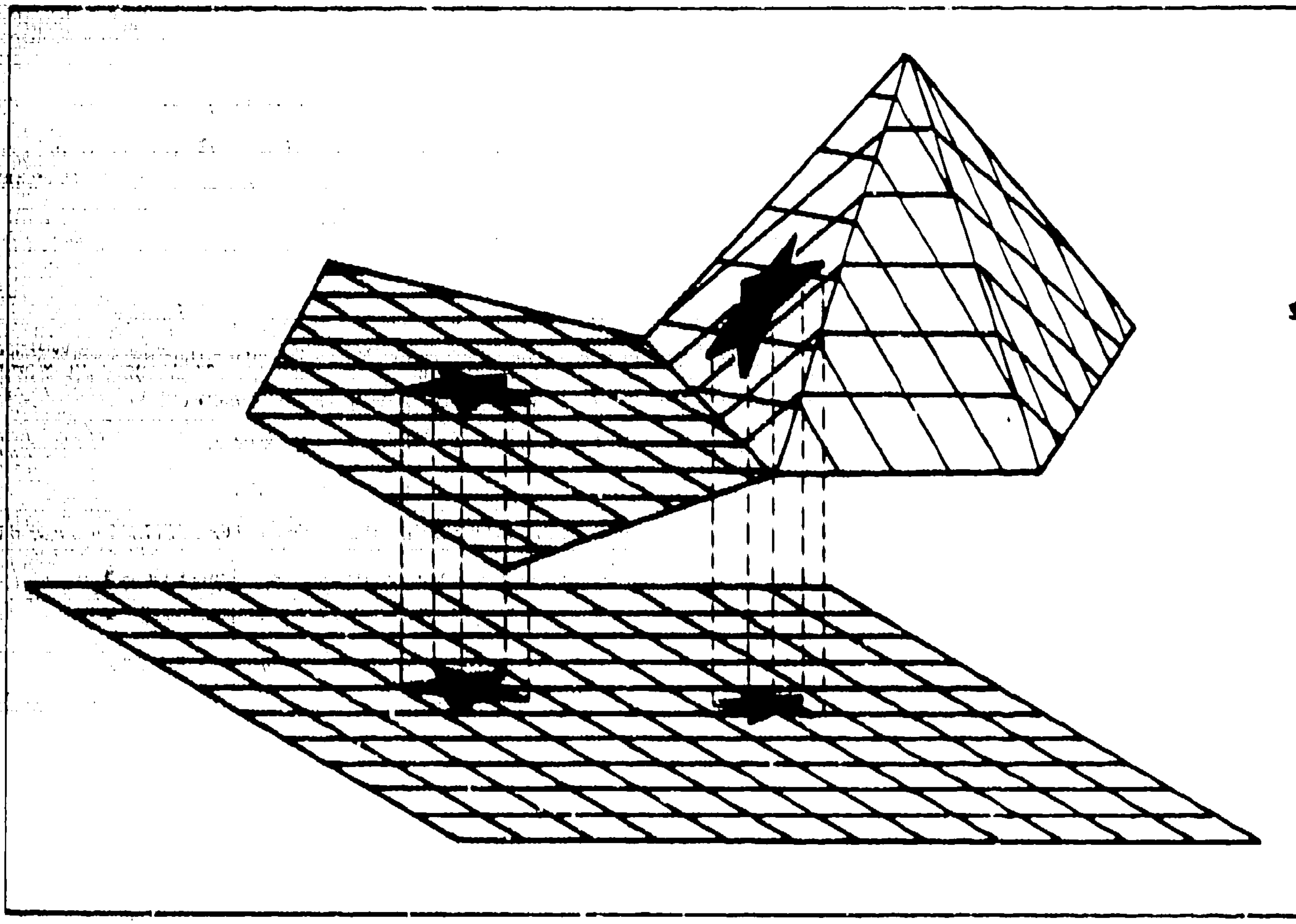

Figure 5.1.5.2.6-1 TEXTURE ON HORIZONTAL AND NON-HORIZONTAL SURFACES

small number of parameters to provide a compact data base. The parameters can be selected to correlate with the statistical characteristics of the real-world features being modeled. Perspective validity can be assured by making the scene position coordinates the independent variables of the texture function. Real-time implementation, as with all CIG algorithms, will require special-purpose hardware.

Several manufacturers are developing texture consisting of regularly repeated patterns, one and two-dimensional, that are superimposed upon the faces of the objects in the image (see Bunker et al, 1978, Reynolds et al, 1978, and Yan, 1980).

To keep the superimposed patterns fixed to the object, either ground-mapped or surface-mapped texture can be used. In ground-mapped approaches all texture patterns are tied to earth coordinates and are projected onto textured faces. Texture is then generated as an intensity variation for each picture element of the simulated image. These variations would then be combined with the scene intensity. In this way bright objects would be textured brightly and dimmer objects textured faintly. One limitation of a ground-mapped system is that texture cannot be applied to vertical surfaces.

Surface mapping is a more general case of ground mapping. It has the advantage that the texture patterns are not distorted as a function of surface (polygon) slope. However, one disadvantage is that continuity of texture across surface boundaries is not guaranteed and also, the coordinate computation is more difficult.

As discussed earlier, the limited computing capacities of current CIG systems make it mandatory that any texture generator avoid processing texture in the pipeline processor. However, a number of additions to current CIG systems are necessary in order to calculate the coordinate transformations to superimpose the pat-

tern(s) upon the image faces. Even when the texture is not being processed in the pipeline, the extent of these additions makes it extremely difficult to retrofit texture into current visual systems. Future CIG systems can make provision for these additions in the early design. In addition to the coordinate calculations, provision must be made to provide codes for selecting and placing texture on any desired polygon in the data base.

One further consideration is that when several levels of texture are provided to be inserted as a function of range, a method of blending the various levels at their boundaries must be included.

5.1.5.2.7 <u>Visual System Data Base Generation</u>

Currently, digital visual data bases are being built in several different ways, depending on the manufacturer and the particular contract requirement.

The most common method, and one that each of the manufacturers has perfected to some degree, is a computer-assisted digitizing approach using a wide variety of input source materials. Most of the terrain data is digitized using lifts taken from U.S. Geological Survey maps, usually the 1/24,000 and 1/62,500 series. Low-level two-dimensional cultural data is also taken from these maps. High-level three-dimensional cultural detail is obtained by abstracting data from civil engineering drawings. In a few cases dimensions are estimated from aerial photos or a combination of map and photo. Color determination is not as clearcut and is discussed separately.

The second method uses Defense Mapping Agency Digital Data Base (DMA DDB). In many cases the use of this data is specified by contract, or at a minimum its use is highly recommended. The DMA DDB can be used manually or semiautomatically in much the same

manner that U.S. Geological Survey material is used. However, much effort is currently being expended to develop visual data base transformation programs that automatically transform the DMA DDB into a data base for real time simulation. Appendix D is a description of the contents of the DMA Data Base.

The initial attempt to use DMAAC for data base generation was with the digital radar landmass system (DRLMS). The requirements of this type of data base called for generalized features of relatively large geographical areas. DMAAC generation in this situation was very successful and these data bases are currently used on various simulations.

Development of accurate highly detailed data bases for visual systems has not found the same success as the DRLMS. A Link study analyzed DMAA data and compared it with other sources of cultural data (namely, aerial photographs and topographical maps). The study centered around two major areas of interest: data omission and digitization errors. Data omission included omission of significant features and shape errors. Digitization errors included clockwise digitization, feature overlap, and reentering (self-intersection).

The study found that in the sparse area selected to be studied, no features were contained in the DMAAC manuscripts. However, vegetation, dry washes, and buildings were found in aerial photographs which, due to the sparseness of the area should have been included as DMAAC specifications state. In denser areas, lakes, rivers, bridges, small towns, railroad yards, dams were missing in the DMAAC data and visible in aerial photographs. Occasionally features were found which were not digitized when features of similar size and attributes in the same manuscripts were included. Also some features in the manuscripts studied were found to visibly overlap. This constitutes a digitization error over and above the inherent statistical error of the DMAAC data.

A transformation system has been developed which automatically transforms the DMA DDB into a data base for real-time simulation of the B-52 E-O viewing system. To enter the system, the user reviews the source data and specifies edge budgets, error tolerances, and visual and infrared models for DMA planimetry feature classes. The DMA DDB is read and reblocked into standard geographical areas; data from different manuscripts, levels, and releases are merged into a composite source file. The user then edits the composite source. The planimetry and terrain are independently modeled into visual and IR representations and progressively simplified (leveled) to meet the specified edge and error budgets at several levels of detail. The leveled planimetry and terrain are integrated into a combined scene model and reformatted for real-time use.

Improvements to this technology in the next five years will include the following. The complexity and fidelity of the transformed scene will increase to accommodate tactical combat rehearsal in real-world areas. Automatic and manual modeling will be integrated into a single-scene construction system which will augment human perception and judgement with automatic processing of details. Data sources other than the DMA DDB, such as large-scale maps, will be used. Productivity will continue to improve, perhaps by an order of magnitude. Off-line diagnostic tools will be developed to detect most data base errors without use of the real-time simulator. Both round and flat-earth gaming areas will be supported. Areas described as city, open forest, etc., without internal detail will be automatically replaced by realistic two-dimensional or three-dimensional texture patterns. Models will be developed for a variety of electro-optical sensors.

In addition, data bases may be developed which are similar to the DMA DDB, but designed specifically to support visual and E-O simulation. New data base designs and formats may be operable on several different CIG systems. CIG throughput analysis may permit

the specification and construction of data bases which consistently use almost all the available CIG capacity without risking overload. Improved understanding of pilot cues may allow translation of training needs into specific testable CIG performance requirements.

Some systems use various combinations of the above systems. In addition, all companies are working on new data base generation programs to make data entry easier (simpler commands, better primatives, etc.) and are also improving the entry equipment by adding interactive displays. It would be highly desirable if the interactive display were coupled with the data base compiler so that the operator modifications were made directly in the real-time data base program. Present efforts, however, require recompiling of the data base in many cases.

5.1.5.2.8 Alternate FDL Data Base Preparation

An alternate method of data base preparation may be of interest to FDL. It has been used in several special cases and may find more use in the future. It is completely computer-generated culture and terrain. Programs have been written that require only a few city parameters (street width, alley width, block size, area of city, and nominal building height) and randomly generate a city that can be displayed immediately in a digital visual system. The same system can also randomly generate terrain, given height and location of peaks, saddles, and ridges. Note that these programs generate both the culture and terrain in a random fashion; hence, the resulting data base only approximates a real-world scene. For flight test purposes this procedure may be invaluable because it can be made to produce a different data base with exactly the same level of complexity for every test flight and, hence, remove the learning curve problem from the flight test.

5.1.5.3 IR Sensor Simulation

IR sensors are either direct viewing or scanning devices (in the latter case they may be mechanically or electronically scanned). Whether the sensors themselves are direct viewing or scanning devices the cockpit displays are universally electronic scanning devices (TV displays) because the data can be more conveniently transmitted. Since the most reasonable IR display is a raster device it is reasonable to assume that the most economical IR simulation device would be the modification of a visual simulator rather than the parallel design of a completely new sensor simulator.

The reasons for these necessary modifications and their possible implementation in the digital visual systems will be discussed in further detail in the following paragraphs.

5.1.5.3.1 IR System Design

A cursory analysis of the types of IR sensor indicates that the slow-scan (mechanical, single element) systems are likely to be completely phased out of use in the next few years. These are being replaced by IR scanners operating at television frame or field rates and by direct imaging scanners. In addition, the future IR scanners may be steerable or head slaved.

These latter devices make it necessary to slew at rates up to 50° per sec without noticeable scene breakup. At these high slew rates it is necessary to update the scene at TV field rates rather than at TV frame rates so as to eliminate the double image effect.

This set of general IR scene generation requirements indicates that the computational requirements are quite similar to helicopter digital visual systems, and it follows that any new IR scene generator would closely parallel present digital visual sys-

tem designs. It appears reasonable to conclude that the best and most economical approach would be to use a digital visual system for IR simulation. A second important reason for this choice is the necessity of providing correlated imagery for all sensors and the visual scene. This will be discussed in more detail later.

Using a digital visual system requires some modification, mainly in the data base structure, to provide IR data to the image processor and to the video generator to generate the correct IR intensity returns and the special effects. Depending on the content of the IR data assigned to objects or faces in the data base, some additional computation may be necessary in the illumination subsystem of the image processor discussed in section 5.1.5.3.2. Figure 5.1.5.3.1-1A, shows the functions of a typical digital visual configuration and B shows a possible reconfiguration to simulate an IR sensor. Notice that this diagram is effectively the same as Figure 5.1.5.2.1-1.

Current digital visual systems also make provision for computing several channels, that is, sensor scenes computed from differing specific points of view.[1] One of these channels can be used for the visual scene, one for the IR sensor displays, and perhaps another for the LLLTV.

This greatly simplifies the problems of providing multisensor data correlated so that all objects are in their correct respective location when the viewer moves his eyes from one type of display to another. This is done simply by using a common digital data base for all sensors. Since the object is described by only one set of polygons (vertices) it will appear properly oriented in

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1 Digital visual image processors are constructed so that different spatial viewpoints can be used to compute the scene for any displays. Most image processors can drive up to seven channels.

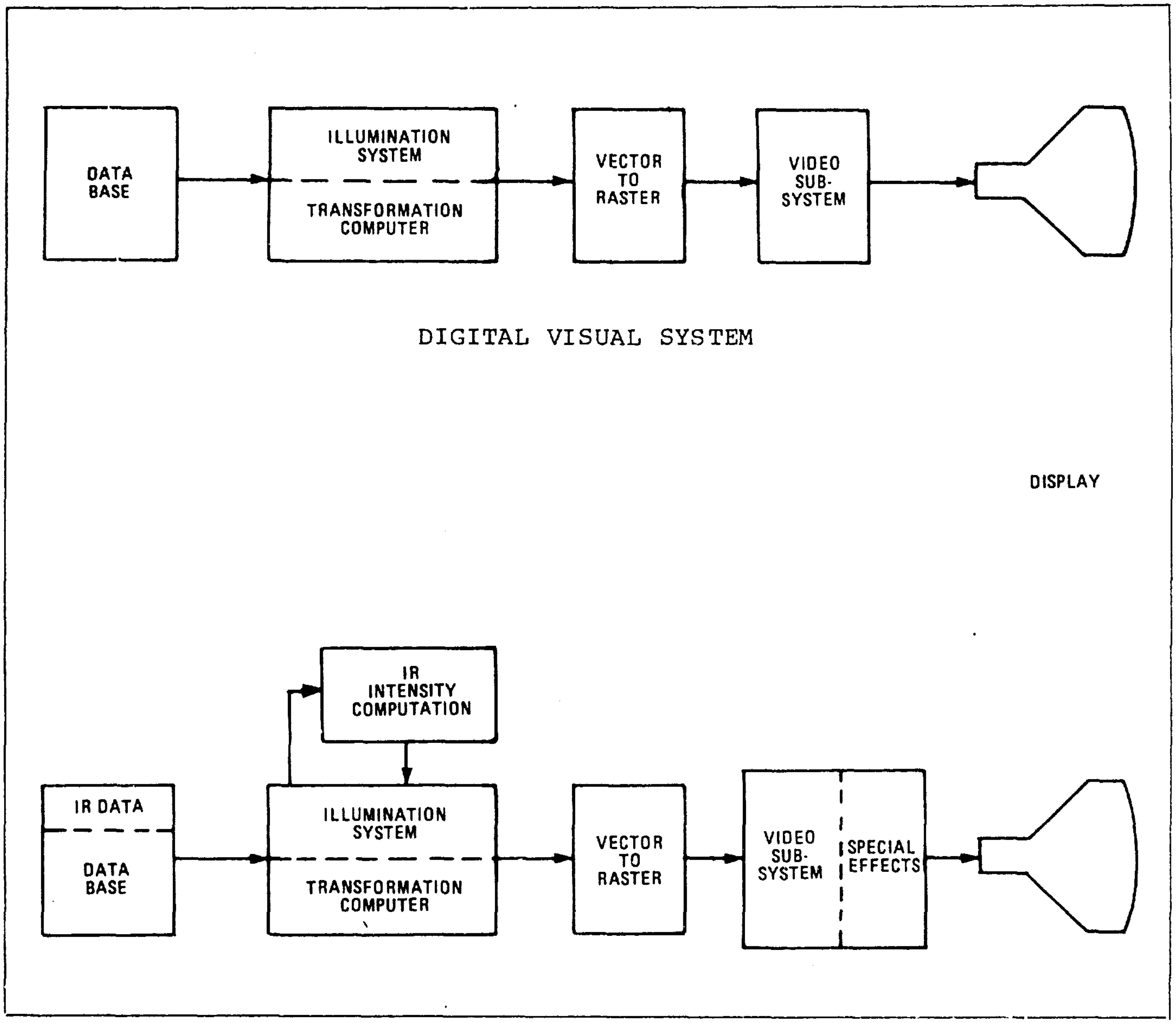

Figure 5.1.3.3.1-1 IR SENSOR SYSTEM

each type of display. Currently, time separate descriptors in the data bases are used by the system for computing the proper IR (or other sensor) scene. This implementation is being successfully employed in the more sophisticated sensor system simulators such as KC-135 and B-52.

The further development of a common multisensor data base is an important goal for both the manufacturers and the Air Force. Some of these investigations are directed toward the inclusion of many additional sensor codes for each object in the data base. Since it has been noted in early IR sensor simulation programs that a further partition of the data base objects may be necessary, these separate codes will describe the appearance of each object at every usable spectral region (the entire electromagnetic spectrum is not usable because of the atmospheric attenuation of radiation at particular wavelengths by the atmosphere. In the IR region, for example, only the 3-5 micron and 8-14 micron regions are useful). This multiple code would then allow several different sensors to be simulated.

This may not completely satisfy new IR simulation requirements because current coding assigns a unique code to an entire data base object. In actuality, objects exhibit different IR properties for each face because of materials, surroundings, etc. It may soon be required that each face of an object be subdivided into a number of smaller elements with each of these subfaces being given a separate code. This would provide further information to the processor to enhance realism.

Currently, the noise inherent in the actual sensor displays completely masks the subtle differences exhibited in the IR radiation of large masses (terrain, foliage, runways, roads, etc.). With the advent of a new generation of IR sensors now being developed these effects will become necessary to provide realism. These effects will have to be treated in the same manner

as texture is handled in some of the latest visual simulators, i.e., with additional data base coding for each face affected so that various texture patterns and pattern sizes stored in the data base can be merged with the face itself in the video generation subsystem of the image processor. This method of texture generation relieves the image processor of the processing of edges for texture effects.

The IR sensor poses additional problems with the size and format of the sensor data base. Since the sensor is usually part of a sophisticated optical system, the FOV of the sensor can be rapidly changed from the wide angle coverage normally used for search to a magnified view as small as 1° by 1° when attempting to identify an object. An attempt to produce a reasonably detailed scene by extraction from a not very detailed data base would show an extremely sparse scene. Figure 5.1.5.3.1-2 helps to illustrate the extent of the problem.

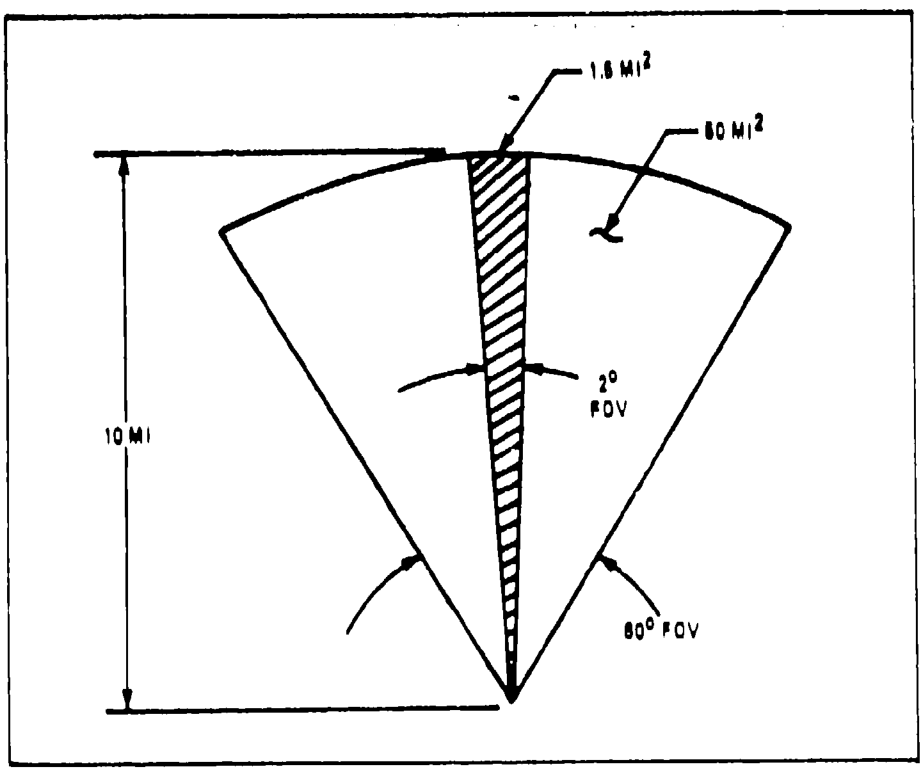

Figure 5.1.5.3.1-2 FOV GEOMETRY

With a 60° FOV and an IR range of 10 mi, the area that must be populated with edges is approximately 50 square mi. If a 30-power optics system were employed (a 2° FOV), the area of interest would be approximately 1.5 square mi. Assuming that a computing capacity is 10,000 edges and a data base were designed so that all edges could be seen at the maximum FOV, only 1/40 of the edges (250 edges) would be in the magnified area. It is obvious, therefore, that either a more powerful data base retrieval system is required (along with better data base generation and data base storage methods) or a priori knowledge of the objects of interest is required. In the general sensor simulation case, the latter is unacceptable, requiring substantial development of more flexible sensor data base systems than those currently in use. However, the FDL has far better control of the mission scenario and may be able to dictate the area (objects) to be scanned or observed with the small FOV IR sensor. This allows the current image processors to be used by taking advantage of the visual system leveling functions, resolvability code testing, and careful partitioning of the data base.

5.1.5.3.2 IR Image Processor Requirements

The image processor for IR scene generation must perform the same geometric processing as required for visual simulation. Both visual and IR sensor image processors must retrieve scene data defined as polygons or edges stored in a data base, perform coordinate transformations of objects, clip transformed objects to the boundaries of the viewing window, delete hidden lines, sort the remaining edges, convert the edges to raster scanline intersections, and produce video to drive a display. The IR processing differs substantially only in the illumination system computation. In the visual image processor color is stored on a polygon basis and the intensity of the assigned color is modified as a function of the incident angle of the sun (or other illumination source) and the viewing angle. The IR return, on the other hand, is far

more complex and therefore requires a more sophisticated intensity computation system.

5.1.5.3.3 IR Intensity Return Algorithm

This algorithm will be a specialized solution of the basic IR radiation equation combined with an atmospheric transmittance equation:

$$N = \frac{\epsilon\sigma T^4}{\pi} \text{ Watts per cm}^2 \text{ per steradian}$$

Where N = IR radiance of the object

ϵ = emissivity

σ = Stefan - Boltzman constant $5.67 \times 10^{-12} W\ cm^{-2} (°K)^{-4}$

T = Temperature (degrees Kelvin (°K))

It appears that the solution to this equation is appropriate for IR simulation. However, the determination of the emissivity and temperature terms for the wide assortment of objects to be expected in an IR data base is a complex task.

The two variables in this equation are emissivity, ϵ, and temperature, T. Emissivity is the ratio of energy emitted by the specified object to the energy which would be emitted by a black body of the same temperature, T. The emissivity of an object may be determined as a function of the material of which it is composed, or of which each part is composed. The basic value must be modified as a function of the surface finish and the shape of the object. For exposed cultural objects, weather effects will greatly modify emissivity. For example, one or more surfaces of the basic object may be coated with rain, ice, snow, soot, or other atmospheric precipitants. Similarly, temperature, T, is a function of sun (as the major energy input source) angle modified by internal heating of the object and weather effects such as

cloud cover, falling rain or snow, or current ambient temperature at the object. The temperature is further modified by recent history, since most objects of interest have long thermal time constants, and store results of preceding weather, sun illumination, internal heating, etc.

The atmospheric transmittance equation is:

$$I = I_A + (I_O - I_A)\, e^{-R' K_1}$$

where:

I = the observed intensity of the object
I_A = the observed intensity of the atmosphere
I_O = the observed intensity of the object at zero range
R' = the ratio of the distance to the object to the visibility distance
K_1 = the scaling coefficient
I_O is related to object IR radiance, N, by a constant K_2

Parameter flexibility is inherent since the visibility range and scaling coefficients K_1 and K_2 can be assigned by program control.

Treating I as a single numerical magnitude is correct for wavelength-independent sensors, such as pyrolitic and other thermal sensors. However, for photon sensors, each object should be provided with emissivity (ϵ) versus wavelength (λ) function tables or curves, and I for each emitting wavelength should then be multiplied by a factor which describes the sensitivity of that particular photon detector at that wavelength. The summation of these results will provide the final detector value, I. Simulation of these effects is possible, since each data base object can have known values assigned for each possible sensor type, and atmospheric windows can be defined for each simulation.

5.1.5.3.4 IR Intensity Return Implementation

It is obvious that the computation to obtain the proper intensity is possible but difficult to implement because, for one, the factors cannot be easily obtained[1] and, secondly, the amount of computation to be performed in real time becomes prohibitive. In a practical case a simpler solution than solving the classic equations is necessary.

One obvious solution is to assign arbitrary codes to each class of objects in the data base. The objects can be grouped and assigned a common code when they exhibit the same general IR properties with respect to extent of emission, cooling rates, etc. The rules for applying the code for objects can be specified to the data base modeler. This arbitrary code will be retrieved with the object record and used to index stored tables that contain the factors necessary for the computation of IR returns. The table serves the purpose of reducing the amount of redundant data that need to be stored in each object record in the data base.

Using an object IR code to index stored tables also makes it possible to provide many levels of sophistication to the computation of IR returns. Partitions of the stored tables and additional codes can be used for new sensors or make use of better IR return intensity data without affecting the design of the image processor.

There are obviously other methods for storing the IR parameters and subsequently computing the IR intensity returns. At this time, however, it is more important to obtain sufficient IR parameter data in a form useful for computation.

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1 Emissivity, for example, is not included in the DMA DDB. In fact, as described in Appendix D, objects of any kind (cultural or natural) are only defined as to their predominant material type.

Further computation beyond that required for determining a standard IR intensity return can also be a combination of table lookup of correction factors or stored functions. These computations can take into account seasonal changes, weather, latitude, and time of day. More subtle effects, such as adjacency effects, may not be computed in the next generation device.

5.1.5.3.5 Special Effects

The IR images produced with the DIG (as described in section 5.1.5.3.3) exhibit the same shortcomings of most digital imagery. The colors and/or intensity of each face are homogeneous and the scene lacks detail. On the other hand, the actual IR image is extremely noisy and contains many artifacts. In other words, the data base and processing limitations create a sparse but clean scene while the actual scene has great detail concealed with noise.

The special effects, as discussed previously, do not originate from a single source but are functions of type of aircraft, aircraft attitude, type of IR detector, transmission chain anomalies, target background, scene dynamic range, absolute target temperature, and many other factors. Some of these effects can quite easily be simulated by analog techniques. For example, transmission and display anomalies can be accommodated with an image converter and TV channel, either included in or after the video processor of the CIG systems (see Figure 5.1.5.3.1-1B).

Some of the other special effects are now being accommodated with a modified video generator. In most cases the IR return is changed on a scanline-by-scanline basis. This works well for effects such as banding, etc., but some effects (such as halo and tail) will require more sophisticated techniques. These techniques will, more than likely, require a full frame output buffer. In addition, much more information must be factored into special

effects to provide the full range of artifacts exhibited by operational equipment. This all but dictates a digital processor dedicated to providing these effects.

The digital processor, in conjunction with a full frame output buffer, would provide a software programming capability for most of the special effects which are presently recognized and would also accommodate the special effects that may be a part of future IR sensors.

5.1.5.3.6 Special Requirements - Semitranslucent Objects

There is a need to produce semitranslucent objects for such real-world objects as localized smog or steam. There are a number of alternative techniques that may be used to produce this effect (see Lewandowski et al, 1980, and Bunker, 1979). Both of these new techniques can be used under certain conditions and produce acceptable (and sometimes dramatic) effects.

5.1.5.3.7 Concealment

In addition to providing texture to the objects and polygons in the IR scene (in the same manner as discussed in the visual scene generation section) it will also be necessary to develop a special kind of texture. The special texture must be provided in the IR scene so that IR emitters can be concealed. At present the sparseness of the CIG scene does not permit making subtle or partially hidden objects because the very presence of objects in the scene indicates importance. Training in search techniques with CIG will require the development of real-time data base, post-processing, and additional hardware in addition to the psychophysical research efforts currently underway.

5.1.5.3.8 Moving Objects

Moving objects are easier to locate and identify in a computer-generated scene than they are in the actual visual scene because the eye is sensitive to motion, particularly in the periphery of vision. In the IR scene these objects are even more important because, in addition to their motion, they also are represented by unique IR signatures. All objects of this class have a concentrated heat emitting source which, except in unique situations such as deserts, are much hotter than the surroundings. This source usually is sufficient to warm the entire object and clearly outline it against the background.

The digital modeling of these objects is relatively straightforward because a large number of IR photos and computer thermal plots (both actual and predicted) are available. The more difficult task is the realistic movement of these objects along the terrain. Current image processing systems require preprogrammed paths, usually along known slopes or along selected areas of the data base. Real-time software written for this task usually limits the path and the number of vehicles that can be accommodated at any one time. A more general solution will have to be perfected so that the vehicles can move anywhere in the data base. This may include a more straightforward solution to establishing the height of the terrain at any arbitrary point in the data base.

5.1.5.3.9 Weapons Effects

Moving objects can move in any direction on or above the terrain, but do not themselves change shape. On the other hand, bomb bursts, shell hits, etc., are dynamic objects. They grow randomly but somewhat predictably; move as a function of wind direction; and change color. An accurate portrayal of the burst image (as opposed to a symbolic portrayal) is extremely important to IR simulation because the observer obtains information from the

shape, growth, and heating pattern of the blast, not simply from its location. The same solution for these effects as for texture does not seem possible. It does appear that a technique that utilizes a real-time data base manipulation technique such as that described by Lewandowski (op. cit.) may provide these effects.

The technique in its simplest implementation is a large number of representations of the burst. Each would be the image of the burst at one time in its growth and decay. These would be stored in the image processor control computer and transferred to the image processor active data base at some predetermined interval of time. (Some present implementations use a 5 or 6-frame time interval.)

The patterns can be grown off-line with a pseudorandom growth algorithm or, in a more sophisticated technique, could be randomly grown in real time. The latter may be preferable for the slow-growth long-period bursts, such as large explosions.

5.1.5.3.10 Summary

The current CIG systems can be considered second generation, the first generation being the CIG test and evaluation devices that had little training value. There was in fact a great technical step between these two generations Early CIG's had perhaps 128 edges and no occulting while current CIG systems provide 6000-8000 edges with at least 256 levels of occulting. It should be noted that these latter devices are using the latest in digital computation and storage technology and, as pointed out in the discussion on image processors, a stable and useful system design common with all manufacturers.

It does not appear likely that an image processor that departs radically from the use of planar surfaces will be announced within five years. In fact, many of the military research pro-

grams that were promoting and/or sponsoring such programs as edgeless CIG have been withdrawn or cut back. Some of this is due, no doubt, to funding considerations but, to a greater extent, it is because the numerous proposed computation systems are difficult, if not impossible, to implement at this time.

There is no question that there is, or will be shortly, a 2-1/2 generation of CGI. The basic image processor philosophy will remain the same but distributed processing may reduce the cost while increasing planar surface computation by a factor of 2 to 4. In addition, the retrieval of scene data will be improved to better populate the scene being presented while increasing amounts of postprocessing of imagery will be implemented to provide a large class of scene improvements (texture, translucent objects, etc.).

5.1.5.4 Digital Radar Landmass Simulation

It would be highly desirable if, as in the case of IR sensor scene generation, a channel of a digital visual system could be modified to generate the digital radar scene. As discussed previously, the planar approach to visual scene processing was decided upon by all CIG manufacturers in order to make digital processing possible (and practical). It also followed that the planar segments are also the most compact digital description of the terrain.

Early in the development of DRLMS radar landmass systems this approach was the subject of intensive investigation (see Hearty, 1972) and several manufacturers have opted for this approach. Even when planar descriptions of the terrain are being used, the hardware solutions to the radar equations and the use of PPI displays have made it impractical to make any of the DRLMS systems and data bases common to the digital visual and senror systems.

Other manufacturers have chosen to use a grid system to encode the terrain (see Hoog et al, 1974). In this type of system the terrain is stored as a rectangular grid of elevation posts. The spacing of the posts is chosen so that through the use of a smoothing algorithm, a sufficiently accurate representation of the ground can be obtained.

The choice of either of these two methods of coding terrain determines the architecture of the DRLMS system and to a somewhat lesser extent the complexity of the DMA DDB to DRLMS data base transformation programs. The latter is an important consideration in that extremely large real-time radar data bases are required that defy manual modeling and digitizing. The effect of the choice of terrain coding on DRLMS architecture and transformation will be discussed further.

The requirements of fidelity in the DRLMS for the engineering simulator differs in one significant way from the fidelity required of a tactical aircraft simulator. The engineering simulator DRLMS must simulate extremely high resolution radars operating at low altitudes (as perhaps the tactical simulator) but does not necessarily have to portray a specific geographic area. The data base must contain sufficiently high resolution data coupled with a compensation technique that provides radar information to the pilot that does not detract from his evaluation task.

With regard to data compression the basic reasons for selecting a planar approach or a gridded approach for an operational aircraft DRLMS are no different than for an engineering simulator.

The planar approach minimizes the need for a large data base storage system and for a sophisticated retrieval system. However, in the engineering simulator there is no need for large (world

wide) maneuvering areas. There is, however, a requirement for displaying the output of extremely high resolution radars operating in NOE flight. It appears at this time that only a gridded approach to DRLMS can provide the necessary high resolution.

5.1.5.4.1 Terrain Representation

The original DMA data for terrain is in a grid format. This makes the transformation to a DRLMS grid format straightforward and easily understood. It is also efficient in terms of transformation processing time since a one-pass conversion routine can be used. A system using planar representations must employ algorithms that create a mathematical surface in a different form than the input data. A more important criterion that must be met in the planar transformation process is to generate a sufficient number of surfaces to accurately portray the scene while at the same time not generating more faces than can be processed in the computer. This makes fitting planar surfaces to a set of terrain data a complicated, iterative process. There is no question that the grid representation of terrain is not as efficient as planar coding since the adjacent posts in level terrain are redundantly coded. Therefore it is a foregone conclusion that more digital storage (and subsequent retrieval systems) is required for DRLMS systems employing equally spaced elevation posts. To some extent this redundancy tends to make modification and updating of the elevation data base easier and more direct since an individual post elevation can be changed to emphasize a peak or valley, whereas to accomplish the same change a new planar face must be generated and all adjacent faces modified to fit the new face.

5.1.5.4.2 Gridded Elevation Interpolation

It is difficult to establish mathematically what the ideal even grid spacing must be to present to the pilot a scene that can be used for training. The usual criterion is that the scene must

contain all significant recognizable terrain features. Early DRLMS systems established that a completely realistic scene can be generated with a grid spacing of six arc-sec for short ranges (up to 25 nmi). This compresses the original DMA by a factor of one. At long ranges (up to 100 nmi) a grid spacing of twelve arc-sec is satisfactory. This latter spacing compresses the original DMA data by a factor of sixteen.

In order to present a continuous terrain surface along retrieval sweeplines, intermediate elevation values are interpolated. Many algorithms have been evaluated and scenes generated using the various schemes. Early DRLMS used a complex weighted parabolic interpolation but more recently simple bilinear algorithms have been developed which also provide a radar prosentation which is free of grid modeling effects or large planar segments.

5.1.5.4.3 Planar Interpolation

The planar segment representation is an extremely compact method of encoding terrain and, over a limited area, is capable of describing the position, shape, and elevation of isolated ground features much more accurately than gridded terrain data. With gridded elevation data some prominent peaks or valleys may fall within the grid and, without manual updating, could be further smoothed during interpolation. However, there is an absolute limit on the number of faces that may be used to describe the terrain. At long radar ranges this results in large geographic areas being defined by a single plane. Small undulations would not appear in the data base at all.

The most noticeable problem is that there are abrupt and unrealistic changes of radar return at the large planar boundaries. These are caused by the abrupt change of aspect angle, etc. A smoothing function, not unlike that used for producing a rounding effect in the visual scene, can be used to minimize the edge out-

lining effect. The large facets that show through on the display are more difficult to conceal. Without intermediate terrain data to make realistic contours the facets must be populated with radar texture in much the same manner as was discussed for the CIG visual scene to achieve some further degree of realism.

5.1.5.4.4 Processing Architecture

The other significant difference in the implementation of the planar and gridded terrain data is in the processing architecture. The planar processor is a combination of dedicated parallel and pipeline processors that perform the necessary mathematical operations in radar sweep time. The computing capacity is designed to process a maximum number of planar segments. As a practical matter the number of planar segments is chosen on the basis of an anticipated average. This is precisely the same limitation faced in CIG.

The elevation grid data processor is not designed to accommodate an average complexity but is designed to accommodate the same number of elevation posts without regard to terrain form. It also is implemented as a pipeline processor with parallel retrieval. Since it is designed to process the maximum amount of data at all times it is more complex and as a result more expensive than the planar processor.

5.1.5.4.5 Reflectance (Planimetry) Data

The cultural data base represents a description of the environment (e.g. water, deciduous trees of 40-ft height, steel buildings of 300-ft in height, residential area of 50% ground cover). All of this data must be stored in digital memory as was the case with the elevation data. There are, as was the case with elevation data, two methods of storing and subsequently processing

the reflectance data -- a grid technique as described before, and a list description.

The same implementation rationale presented for representing elevation is valid for representing cultural data. However, whereas the grid system is particularily suited to storing and presenting data which is uniformily distributed (e.g., terrain data) it is not an efficient method for storing cultural data which is normally not uniformly distributed.

In early DRLMS systems a grid system was used but as higher resolution data became available most manufacturers have opted for a list processor or a hybrid list and grid processor. Table 5.1.5.4.5-1 shows the salient characteristics of elevation and cultural data base formats, and resolution, for several DRLMS systems delivered to the Air Force and Navy.

Early analysis of the DMA DDB indicated that only up to 80 features per nmi need be processed in the DRLMS. However, DMA is now providing data bases with feature densities of over 250 features per nautical mile over extended areas.

It would appear at first that with the high density of cultural data it would be possible to use a grid approach for the design of the elevation system for the reasons stated previously -- simplicity and cost. However, the resolution of the cultural data is about 30 ft. In order to preserve the separation between objects it would be necessary to use a grid spacing 2 to 4 times finer than this spacing. This would be impractical in terms of both data base storage and processing. DMA made the same conclusion when they established the format for cultural data and subsequently coded the data in a list format.

Table 5.1.5.4.5-1 DRLMS DATA BASE COMPARISON

		ELEVATION DDB			CULTURAL DDB				
DRLMS	DATA SOURCE	FORMAT	HORIZONTAL RESOLUTION	VERTICAL RESOLUTION	FORMAT	HORIZONTAL RESOLUTION	REF CODE	VERTICAL RESOLUTION	RANGES SUPPORT
F-4 and F-14	Digitized transparencies	X-Y lambert grid	1000 ft	25/50/100 ft	X-Y lambert grid	250 ft	3 bit	25 ft	5-50 nmi
Project 1183 (F-111A)	DMA	Lat/long grid	3 arc-sec (300 ft)	10 ft	Lat/long list	0.15/0.62 arc-sec (15/62 ft)	4 bit incl. directionality and height	20 ft	5-30 nmi
EA-6B	DMA	X-Y lambert grid	1000 ft	8 ft	X-Y lambert grid	250 ft	6 bit incl. directionality and height	8 ft	27 nmi
C-130	DMA	Lat/long grid	6 arc-sec (600 ft)	8 ft	Lat/long grid and list	30 ft (list) 100/200 ft (grid)	5 bit incl. directionality and height	8 ft	3-30 nmi
B-52	DMA	Lat/long grid	6 arc-sec (600 ft)	2 ft	Lat/long grid and list	30 ft (list) 100/200 ft (grid)	5 bit and directionality and height	8 ft	5-50 nmi

In the past, manufacturers used a parallel cultural processing system: a grid system for coarse cultural data, and a list system for fine or higher resolution data. This system was adopted so that when the list processor became overloaded (because of limited processing capability) the coarse cultural data would continue to be processed and presented on the radar display with some of the high resolution data overlayed on a priority basis. This parallel system is an expensive method for alleviating the overloading problems. The advent of faster processing integrated circuits and the lower cost of high-speed digital storage will make it possible to use a single cultural list processor no matter how dense DMA encodes cultural data in the future.

An added advantage accrues when using a single list system for the real-time DRLMS data base in that the DMA cultural data base is encoded in this form, thus making computer transformation easier and more straightforward.

5.1.5.4.6 Future DRLMS Systems

The DRLMS systems have progressed in parallel with the CGI systems. The first prototype systems were developed as recently as 8 years ago to show that digital techniques could produce radar displays useful for training. The early systems used small data bases manually digitized from T-10 data or Air Force prediction data. Table 5.1.5.4.6-1 shows the progression in the performance of the systems. The B-52 DRLMS meets the performance specification and more than likely is capable of meeting the radar requirements of the next few years. It uses nearly all of the resolution of the DMA data base.

Improvements in DRLMS are currently being made to accommodate the next generation of military radars. In performance they will eventually use the entire elevation and cultural contents of the DMA data base and use significantly more reflectance codes. At

Table 5.1.5.4.6-1 CHARACTERISTICS OF CURRENT AIRBORNE RADAR SYSTEMS

AIRCRAFT	RADAR	RANGES OF INTEREST (nmi)	PULSE WIDTH (µs)	AZIMUTH BEAMWIDTH	DISPLAY SWEEP LENGTH (in)	DISPLAY SPOT SIZE (in)	DISPLAY RESOLUTION (ft)	ANTENNA SCAN RATE (°/s)	SCAN AREA	PULSE REPETITION FREQUENCY (Hz)	SWEEP DENSITY [illegible]
B-52	[illegible]	5, 10, 15, 20 30, 40 60, 75	.35 .50 1.0	1.5° 1.5° 1.5°	10			[illegible]	360° PPI 30°–360° sector	[illegible] [illegible]	[illegible] [illegible]
F-4C	[illegible]									[illegible]	[illegible]
F-15		10, 20, 40 [illegible]									
RF-4C	[illegible]	5, 10, 20 40	.2	2.5°	4.5 4.5	[illegible] [illegible]					
F-111A/E (FB-111)	[illegible] [illegible]	5, 10 [illegible] 30	.4 .4	1.6° 1.6°	7.0 7.0	[illegible] [illegible]	[illegible] [illegible]	74	[illegible]	2002	[illegible]
F-111D	[illegible]	2.5, 5, 10 20 30, 40	0.1 0.4 0.4	1.7° 1.7° 1.7°	[illegible] [illegible] TV [illegible]	[illegible]	[illegible] 240 [illegible]	90	[illegible]		
F-111F	[illegible]	2.5, 5, 10 20	0.2 0.4	[illegible] [illegible]			[illegible] [illegible]	74 40 [illegible]	[illegible]	2002	22.32
A-7		5, 10, 20 40	0.2 1.0	2.5°					[illegible] [illegible]		
[illegible]											
C-130E [illegible]	[illegible]	3–30 8	0.3 0.2	2.6° 0.7°				12	360° PPI 30°–360° sector	[illegible]	27.38 [illegible]
KC-135	[illegible]	3–30 50–100–200	.35, .8, 4.5	3°					360° PPI 30°–360° sector	[illegible] 1.25	

that time it will be necessary to design a new data base to support radar of higher resolution and better performance. This will be a major undertaking and will not be available during the 1980's.

The most significant DRLMS improvements will be in the simplification of the hardware due to the introduction of integrated circuits with better performance than presently available. Further redesign should minimize the number of cards and the number of types of cards, which will reduce cost and make production, test, and maintenance easier.

5.1.5.5 Analog Radar Landmass Simulator (ARLMS)

The existing FDL facility contains a T-10 Land ARLMS system of late 1960's or early 1970's vintage. The system consists of a data base stored on film plates which are accessed using a FSS. The resulting video is processed by analog circuits which modify the video to be representative of random radar return signals.

The film plates are 30 in. by 30 in. color transparencies. These tri-color plates used in ARLMS for navigation and bombing are described as follows:

Scale - 1 to 3,000,000
Coverage area - 30 in. by 30 in. (1,230 by 1,230 nmi)
Real-world coverage area - 1.5 million square miles
Encodement levels - 392
- Coarse elevation 7 levels - Yellow - Blue PMT
- Five elevation 8 levels - Cyan - Red PMT
- Cultural data 7 levels - Magenta - Green PMT

The maximum resolution of encoded data is depicted on the transparencies at 0.001 in. DMAAC magenta resulting in a ground resolution of 250 ft (often degraded to 500 ft by film limitations).

Tri-color transparancies were originally developed for the T-10 Radar Landmass Simulator by the Marquart Corporation, Pamona, CA. Later versions of these same transparencies were also used by the U.S. Air Force in F-111A radar landmass simulators developed by Link.

The transparencies of the East and West Coast U.S. were developed and produced by Technicolor Corporation, Burbank, CA, between 1963 and 1966. Between 1967 and 1978 the U.S. Air Force Cartographic Technical Squadron (CTS) located at March AFB, CA., was responsible for production and updating of fourteen different geographic areas, amounting to 1.5 million square miles.

The resolution of the encoded data on the tri-color transparencies was scale-limited at 250 ft. If the scale of the transparencies were 1:1,000,000 the resolution would improve to 83.33 ft, and so on.

In 1978 the CTS unit stopped production of tri-color transparencies after building up an inventory of spares of each area, which are available from USAF Defense Mapping Agency Aerospace Center, St. Louis, MO. 63118, ATTN: Mr. Joseph Weltig, or Mr. Richard Batista.

The spot size of the flying spot scanner was 0.001 in. Due to retriggering of levels based on variation in transmission from the center to the edge of this large 30 in. by 30 in. transparency a series of quantizers were used to adjust each and every transparency in the system. If the geographic area plate was changed the entire system needed to be realigned.

Figure 5.1.5.5-1 shows how these transparencies were produced up to the stage of the tone masks which were printed onto the color film.

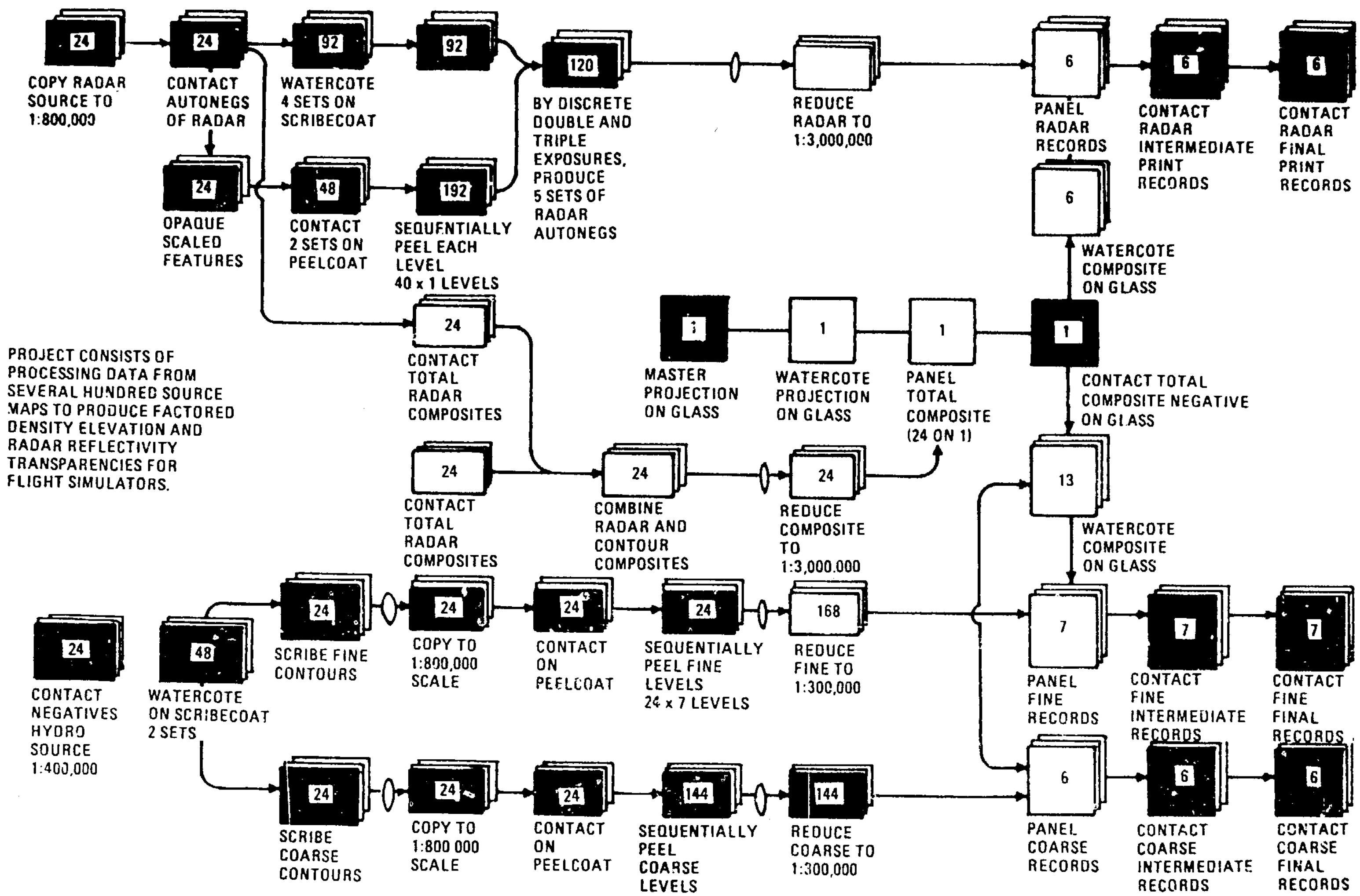

Figure 5.1.5.5-1 PROCEDURE TO PRODUCE T-10 RECORDS

In summary, if the 250 ft resolution is suitable, several transparencies currently exist and are available from DMAAC as previously mentioned.

If resolution better than 250 ft is required, the system can accommodate scale modifications to 1:1,000,000, which will improve the ground resolution represented to 83 ft.

It would take approximately 18 months to set up and produce a tri-color transparency. Updating existing transparencies could be done in approximately 9 months.

It is clear that extensive efforts will be required if significantly increased performance is to be achieved in the existing T-10 ARLMS. Minor performance improvements can be gained through upgrading the flying spot scanner, but these changes cannot bring system performance beyond the limitations imposed by the film plates.

Table 5.1.5.5-1 compares the performance of a digital system with a T-10 analog system. Actual numbers of the DRLMS may vary depending on model. The performance of the T-10, of course, depends on age and maintenance. The table represents original performance achievable.

Table 5.1.5.5-1 T-10 ARLMS VS. DRLMS PERFORMANCE

PERFORMANCE PARAMETERS	SIMULATOR CAPABILITY ANALOG	DIGITAL
Positional accuracy	>1000 ft	250 ft
Resolution	500	<250 ft
Pos drift	?	None
Data base change time	>1 hr (need recalibration)	<5 min
Mission area	1250 by 1250 nmi	Unlimited
Retrieval errors @ 80 nmi	≈4 nmi	0.1%
Cultural levels	7	16
Elevation range	Sea Level 12,800 ft	-2,000 ft 30,000 ft
Elevation steps	56	>4,096
Elevation step resolution	100 ft min - 1,000 ft. max	2 ft
Data base update on-site	No	Yes
Data base quality	Not representative	Best available if DMAAC used
Future and advanced data bases	None	As available from DMAAC
Resolution expansion possible to 100 ft	No	Yes
Resolution and feature quality expansion 35 ft	No	Yes
Fidelity of aspect	?	Excellent
Fidelity of low-level presentation	?	Excellent
Fidelity of shadow	?	Excellent
Fidelity of slant range	Good	Excellent
Fidelity of azimuth	Inadequate	Realistic

Table 5.1.5.5-1 T-10 ARLMS VS. DRLMS PERFORMANCE (Cont'd)

PERFORMANCE PARAMETERS	SIMULATOR CAPABILITY ANALOG	DIGITAL
Fidelity of vertical antenna	Good	Excellent
Fidelity of pulse stretching	None	Excellent
Targets	None	Yes
Beacons	None	Yes
Jammers	?	Yes
Fidelity of weather	?	Excellent
Weather area	?	50K nmi^2 area
Weather levels	?	7
Weather shapes and structure	?	Unlimited
Expandable for		
Air tgt occult	?	Yes
Jammer occult	?	Yes
Longer ranges	?	Yes
Worldwide flight	?	Yes
Seasonal effects	?	Excellent
Extensive diagnostics	?	All
Commonality with B-52/ C-130	?	90%
Interface	?	Computer to computer
Interface to indicator	?	Video

5.2 DISPLAY CONSIDERATIONS

5.2.1 Head-Up Display Considerations

The use of HUD to present sensor information to pilots is becoming an increasingly common practice. In this situation imagery obtained by LLLTV or FLIR is displayed on a CRT unit. The image is then relayed through a collimating lens and is presented to the pilot via a beamsplitting combining glass. The pilot views the resulting imagery, apparently at infinity, superimposed upon the out-the-window scene.

Incorporation of such a system presents some unique problems in a flight simulator, the nature of which will be discussed in the following paragraphs.

5.2.1.1 Integration of HUD and External Displays

The integration of the HUD with the out-the-window scenes can pose problems depending upon the methodology chosen for the display of the external or out-the-window scenes.

Two of the most popular current methods of furnishing external visual displays are curved screens or dome systems, and mirror and beamsplitter collimating systems.

Screen systems are not truly collimated, but rely on using radii of curvature and image distances sufficiently large so that parallax errors due to pilot head motion are small. However, the HUD (usually the actual aircraft hardware) is truly collimated at infinity and hence anomalies are noticed with pilot head motion, perceived as relative motion between the HUD and external imagery, which can be crucial in weapons delivery missions.

The solution to this problem can be found in modifying the HUD optics to image the HUD at the same distance as the screen. Such modifications can be simple for single glass systems in that the HUD can be modified to refocus the displayed HUD image at the screen distance, either by simple change to the collimating optics or internal adjustment of the image display CRT unit in the HUD.

In some cases dual combining beamsplitters are used in order to expand the head motion envelope over which the HUD imagery can be viewed. This case is somewhat more complex, since refocusing can lead to double imaging in the zone of overlap between the beam splitters. In general, the range of brightness available from HUD units is more than adequate compared to the levels achievable from the out-the-window scenes. This permits coating of the combined glasses to reduce the double imagery to negligible proportions.

When mirror and beamsplitter systems are used to yield fully collimated out-the-window scenes one can only generalize as to the compatibility problems posed by the HUD system due to the wide variety of possible external display configurations. The out-the-window imagery is usually collimated at 33 ft (0.1 diopters) as a minimum, but in practice the center of the field near the HUD axis is typically collimated at 60 ft; hence problems are rarely encountered in optical compatibility between the HUD and the out-the-window scenes. The most common difficulties encountered are mechanical interference and ghost images formed by spurious reflections of the HUD image from the external display optical components.

These problems can be minimized by judicous selection and placement of the external display systems.

5.2.2 HUD Image Generation

In cases in which HUD sensor information is displayed in conjunction with out-the-window images perhaps the most obvious solution is to display the normal scenery in the out-the-window displays. The HUD imagery is then separately generated and superimposed optically as in the actual aircraft.

An alternate possibility is to use a dummy HUD system, in order to preserve the cockpit configuration, but present an integrated composite sensor and out-the-window scene in the external displays. The generation of such imagery presents difficulties in CMS's and other systems but is a possibility in the case of CIG.

Conceptually the CIG system could process both the normal and sensor image picture element by picture element and within the FOV of the sensor system display that element with the higher brightness. Such an implementation will require that the HUD image brightness controls be supplied to the CIG so the pilot can influence the sensor display imagery brightness levels in the same manner as in the real world. The question of the cost effectiveness of such an approach is outside the scope of this study, but the technical capability is evident within the state of the art.

5.3. VIDEO PROCESSING

5.3.1. Scan Converter

A scan converter will probably be a necessary item in the simulated sensor system. Multiple video sources will be available, such as from a CMS, a CIG, a radar landmass simulator and probably various symbol generators. If these systems are operating at various scan rates and if a common display device, such as a multifunction display (MFD) is to be used, which operates at some fixed scan rate, then a scan conversion has to take place.

An analog scan converter (CRT and camera) or a DSC (read and write memory) could be used in this application. However, the radar simulation presents another problem. If the radar video is generated in a fixed format, such as a PPI scan, and if other formats such as beta scan or spotlight modes are desired, then the DSC has to be used. Coordinate transformations are achieved with various reading and writing schemes of the digital memory. For long term applications with maximum versatility, the DSC is the best choice. Reliability, stability, and the relative ease of implementing future modifications make it more attractive, in spite of the higher initial cost, than CRT analog converters. Some of the companies which manufacture DSC's are Sperry Flight Systems (Phoenix, AR), Hughes Aircraft Company (Culver City, CA, Cardion Electronics (Woodbury, NY), and Interand Corporation (Chicago, IL). Figure 5.3.1-1 shows a general block diagram of a typical system application of a DSC.

5.3.2 Special Video Effects

The following special video effects can be considered for sensor simulation purposes. Some of these controls may be available in present or future flight systems while others may be useful for evaluation. They may be implemented by adding them to a DSC as illustrated in Figure 5.3.2-1 or they could possibly be added to some of the video generating systems such as the CIG. The special effects are:

1) Gain/polarity control - A gain factor of zero to two, either continuous or in sixteen step increments, would probably be adequate. This could be used to simulate sensor signals under less than ideal conditions and could be controlled by the instructor or software. A video polarity reverse can also be incorporated with the operator having control. This feature could improve display discernment under certain circumstances.

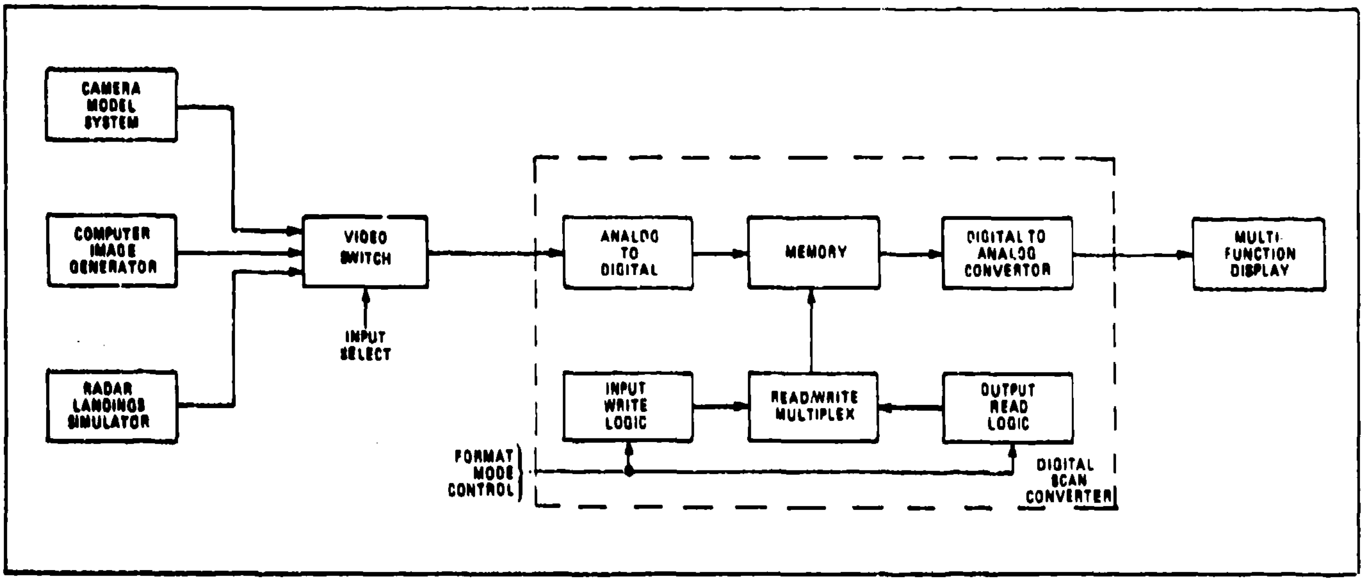

Figure 5.3.1-1 DIGITAL SCAN CONVERTER APPLICATION

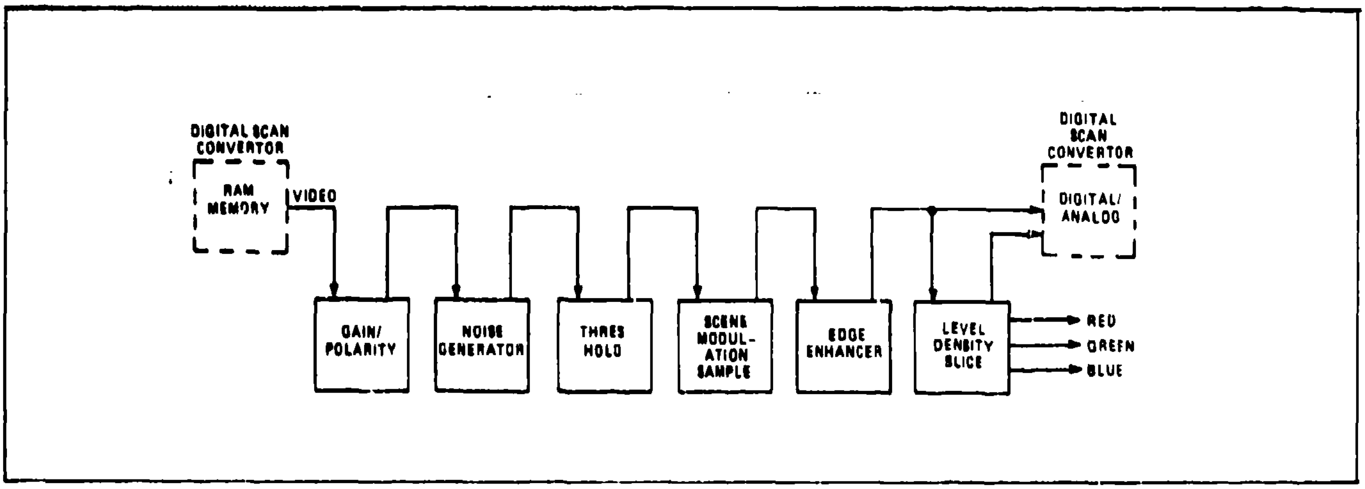

Figure 5.3.2-1 SPECIAL EFFECTS APPLICATION

2) Noise generation - Under various conditions, the introduction of random noise, may be desired for the more realistic simulation of a sensor display. A variable level of noise, from zero to peak white, could be instructor or software controlled.

3) Thresholding - A variable threshold level could be set by the operator whereby only video levels above the threshold level would be displayed. A second mode could also be available with only video levels below the threshold level displayed. This feature could remove some of the display video which may not be of interest.

4) Scene Modulation Sampling - Areas of a sensor display could be sampled to detect the amount of video modulation. If an area had low modulation (e.g., variation of scenic detail), it could be deleted. This feature would probably be used most often with simultaneous sensor presentations, where the video from another sensor could be automatically substituted in the low modulated areas of the primary video which was deleted.

5) Edge Enhancement - The edges of an object could be sensed and made brighter in order to make the edges or the object more apparent. The object with the enhanced edges could be displayed in one mode or the object could be deleted and only the edges displayed in an outline only mode. The intensity of the outline could be made variable with control by the operator. Edge enhancement techniques could improve object recognition or detection.

6) Level/Density Slicing - The number of grey levels between black and peak white can be reduced in order to make certain areas with many gradual changes in density

more apparent. This could possibly enhance certain display features. For example, if a system contained 256 grey levels, they could be reduced by a factor of eight thus making only 32 density levels available instead of 256. Another mode of operation could limit three different video levels at predetermined thresholds between minimum and maximum brightness levels. Video levels falling within each of these intensity areas could be displayed in a different color, resulting in a pseudo color display. The lower slice could be blue, the middle slice could be green, and the upper slice could be red. This would probably be useful for infrared presentations.

5.3.3 Simultaneous Display

Past studies have indicated that it may be beneficial to view more than one sensor video source on a single cockpit display at one time. Simulated sensors such as radar, IR, and TV, along with stored data such as cartography and symbol generator video, are typical data sources to consider. A possible method of implementing such a task is to select one of the video sources and establish it as primary video and select a second source and establish it as secondary video. The secondary video would have to be processed, if necessary, to match the format, line rate, field of view, etc., of the primary video and then mixed in such a manner that it would complement the primary video scene. The final scene could also include symbol generator data. A method could be available to drive either a monochrome or color display with a pseudo color scheme. Two DSC's would be an integral part of a simultaneous sensor display system. A DSC might already be available in a regular simulated sensor display system while a second DSC would have to be added for the simultaneous system. This additional DSC would contain a transformation module which would be necessary if sensors with different formats were to be superimposed. Radar

video for example is normally presented as azimuth versus range, while TV and IR video is presented as azimuth versus elevation. Compensation for any other anomalies, such as line rates and FOV's could also be accomplished with the scan converters.

Figure 5.3.3-1 illustrates the manner in which a monochromatic or black and white simultaneous simulated sensor display system could be implemented. Figure 5.3.3-2 illustrates a pseudo color system.

Four examples of possible combinations for simultaneous display are:

Primary Source	Secondary Source
1) Radar (RLMS)	Stored Cartography (Image Symbol Generator)
2) Radar (RLMS)	IR (CIG)
3) IR (CIG)	TV (CMS)
4) TV (CMS)	IR (CIG)

In addition to the combined video sources, symbol generator video can also be added. In a monochrome or black and white system, symbols could be slightly brighter than normal peak white video, or they could have a black outline, which would make them more distinguishable if they were presented against a white background. The inputs of the final summing amplifier could be easily adjusted with the proper gain. The selection of the desired input video sources could be either manually or automatically controlled. The coordinate transformation would also be controlled depending on which sources were selected. In a monochrome system, the gain of the secondary channel could be slightly less than the primary channel. This might give a less cluttered appearance to the display and would let the secondary serve more as a background reference. The proper gain ratio could be set in the initial sum-

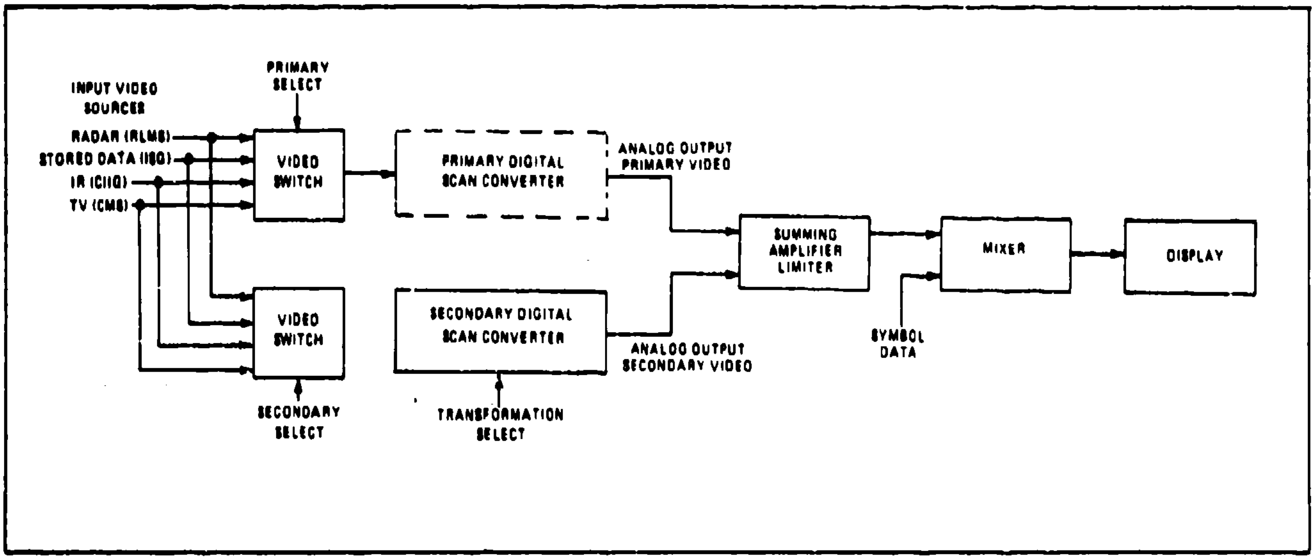

Figure 5.3.3-1 MONOCHROME SIMULTANEOUS DISPLAY SYSTEM

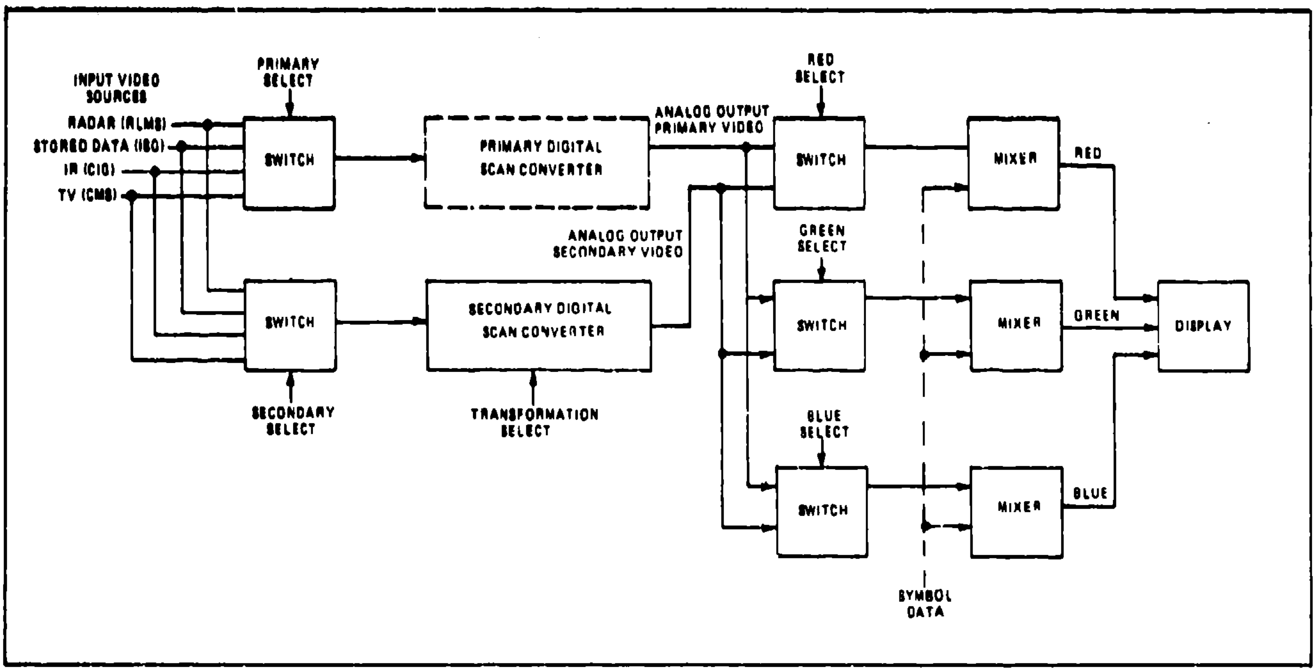

Figure 5.3.3-2 PSEUDO COLOR SIMULTANEOUS DISPLAY SYSTEM

ming amp. In the color system, a suitable presentation could be achieved by making the primary source green and the secondary source blue. When IR is used as a secondary source, only hot-spots could be limited at a predetermined threshold by DSC video processing circuits and added to the scene. If only IR hot-spots were displayed in the color system, they could be presented in red. White symbol generator data would probably be satisfactory even in the color system; however, if color symbols were desired, they could easily be brought in separately to the final mixers and appropriately keyed. The monochrome and color systems could easily be combined if desired since the requirements up to the outputs of the DSC's are identical.

5.3.4 Simulating Sensors with Video Processing

A Visual Sensor Simulator (see McCormick, W. et al, 1978) was developed as an economical method for solving the problem of simulating airborne visual sensors for pilot testing. The system was designed to present representative imagery and not actual target signatures, but it has to be fully acceptable to the pilot. A generalized approach to this sensor simulation has as its primary electrical signal input a TV vidicon that is responding to a visual scene generated either from a terrain modelboard, a motion picture, or a video tape recording.

The sensors considered were the FLIR, FLR, LLLTV, and SAR. For realistic simulation the elements of scene definition, atmospheric effects, and specific sensor characteristics must be closely approximated. Scene definition includes resolution, reflectivity emissivity, thermal inertia, and contrast. Atmospheric effects include all noise and spectral dependent attenuation effects. SNR, modulation transfer function, and signal compression are included in specific sensor characteristics.

The primary analog sensor simulator input is generated in all cases from a TV vidicon; therefore, it is restricted to target reflectivity properties. A correlation must be made between the reflectivity and those target properties relevant to the particular sensor. Processing the vidicon signal which is assumed to be noise free is generally accomplished by the addition of noise to the signal, and by edge enhancement of the target to simulate hot spots as in FLIR, and specular returns as in FLR and SAR coherent radars. The processing continues with the simulation of the linear transfer function followed by a zero memory nonlinearity (ZMN) designed to simulate signal blooming, gray-level compression and target reflectivity, and emissivity effects.

In the FLIR simulation, complexity occurs in the accurate modeling of the scene's thermal emissivity. For accuracy in the simulation, visual reflectivity must relate to infrared emissivity and also account for the thermal inertia effects. The reflectivity and emissivity sum to unity, but the visual and IR wavelengths are different. Thus, in the FLIR sensor, this relationship is not accurate; however, it gives insights into such a relationship. The indication is that bright TV areas will generally be dark IR areas. The simulation is done to reflect this principle and there is no fast relationship between reflectivity and emissivity. The thermal inertia effects are also not taken into consideration.

In the simulation for LLLTV sensors, the sensor responds to the same reflectivity as the vidicon. Thus, no distinction needs to be made between the target and the background during processing. A delay circuit is inserted after the modulation transfer function to provide for image lag effects and the final stage ZMN could be adjusted for signal blooming.

In FLR sensor, the ideal system would be a polar coordinate-based system, since it is desirable to display range and azimuth

directions of the target. The system described is unable to convert from the raster scan (rectangular coordinate) system to the PPI (polar coordinate) system. It is assumed that slant range would be uniform over the area of usage of this particular system; therefore, the coordinate problems would not be significant and the rectangular scanned CRT would be acceptable.

The SAR sensor was not included in the final system implementation. It could probably be implemented, however, by simulating the microwave scene reflectivity with dedicated target and background ZMN's. Edge enhancers would simulate the specular nature of the scene and the overall effects of shadowing.

The system described above was said to be acceptable to the pilots and because of its analog implementation there was scope for the development of additional capabilities. The system, however, suffers from some major drawbacks. The system was designed to present representative imagery and not actual target signatures. The design study was based on various target signature data but the correlation of sensor return for comparison with target signatures was not included. In the FLIR simulation there was no fast relationship between visual reflectivity and infrared emissivity; therefore, the sensor is subject to errors. In the FLR sensors the problem of range was deemed insignificant and therefore left unsolved. With these drawbacks noted the system needs additional study to make it fully acceptable for advanced simulation of these sensors.

5.4 VIDEO SWITCHING

Active solid state video switching can be accomplished by basic off-the-shelf switching units which are available from several vendors such as Dynair Electronics, Incorporated (San Diego, CA), and Dynasciences (Blue Bell, PA). These switching systems are generally expandable by simply plugging in additional

modules. A typical switching requirement would be to switch one of several different video sources, such as a FLIR or TV system or an alphanumeric generator, to a particular output, such as a dedicated line or a multifunction display. This type of application is shown in Figure 5.4-1A. A further expansion of this type of system application is shown in Figure 5.4-1B.

Figure 5.4-1A can be considered 3 by 1 switching matrix. Any of the three inputs can be placed on the output with the appropriate control input. Figure 5.4-1B can be considered a 6 by 2 matrix. Any of the six different inputs can be placed on either of two outputs. As an example, a Dynair switching unit can accommodate up to two 6 by 5 switching matrices by plugging in the full complement of switches (12) and output amplifier modules (10).

A dual 6 by 5 matrix can be represented by the illustration in Figure 5.4-2A. By interconnecting the switching unit as shown in Figure 5.4-2B, an 11 by 9 matrix can be created. It becomes apparent that various switching possibilities can be created by various configurations of the switching units. The control inputs can be driven from switches or can be computer (logic) controlled. Switching unit bandwidths from various manufacturers are typically in the 20-30 MHz range with switching speeds of about 5 μsec.

5.5 VIDEO INSETTING

Electronic methods for insetting one TV image into a second TV image have been known since the early days of commercial television. Also known as a special effects system, this method switches two synchronized video signals so that a portion of one signal appears as an inset into the other. The switching signal that causes this inset may be derived either from externally generated electronic waveforms or from the amplified and clipped output of a video signal.

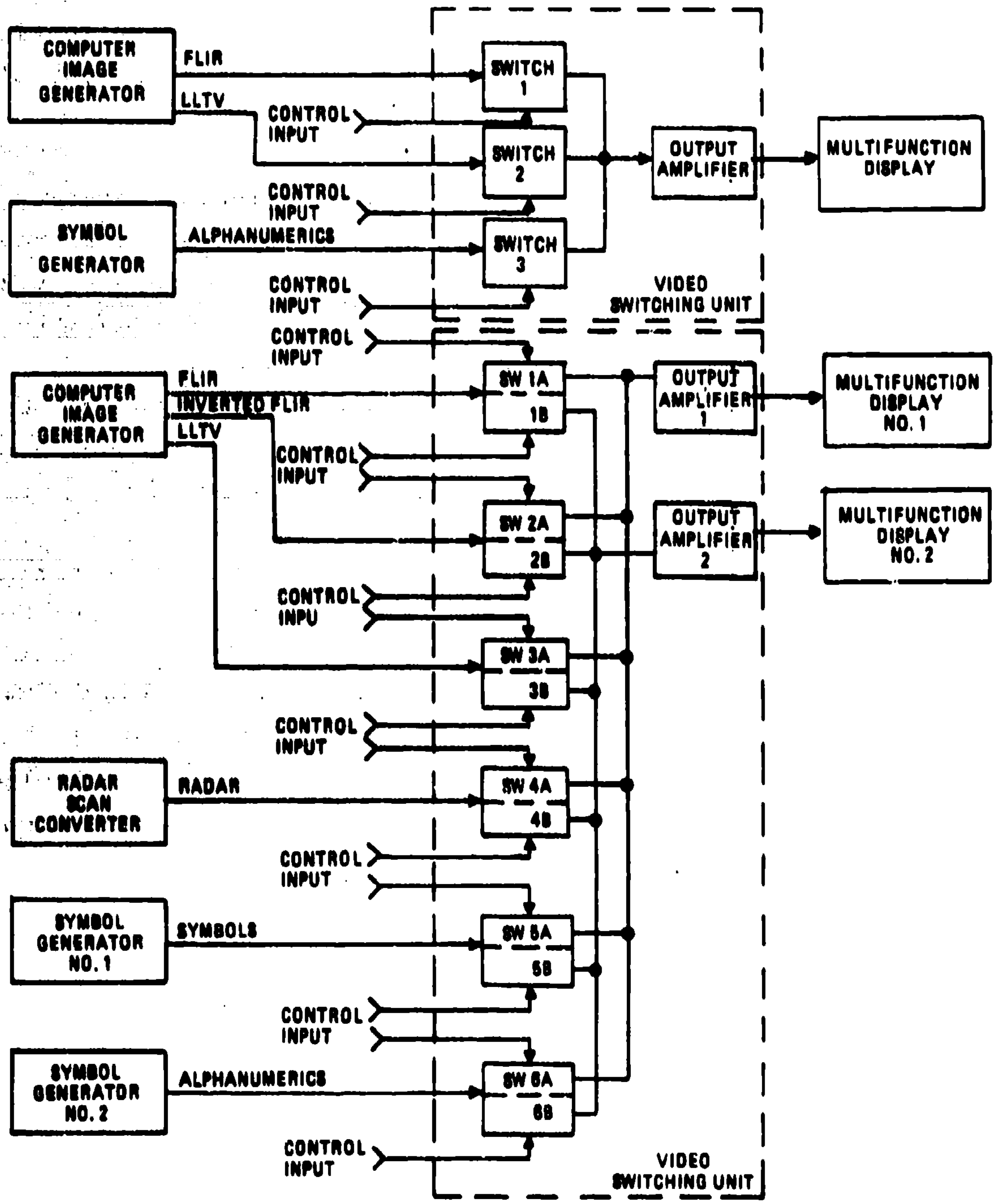

Figure 5.4-1 SYSTEM APPLICATION FOR VIDEO SWITCHING

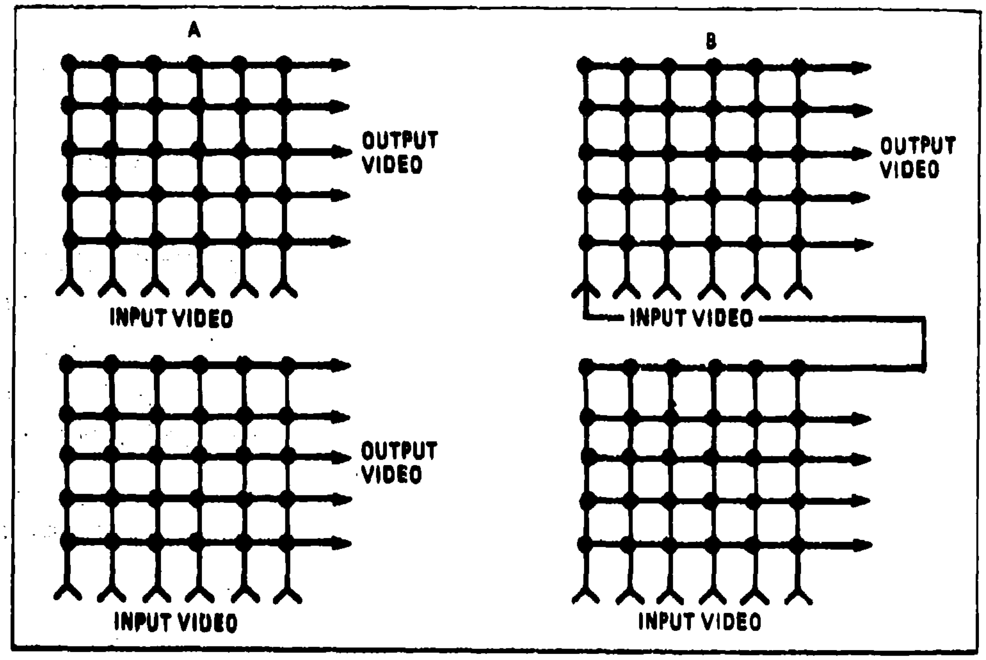

Figure 5.4-2 SWITCHING MATRICES

Video insetting is the technique of presenting video from two different sources on the same TV raster. Each video is mutually exclusive of the other, i.e., only one is displayed at a time, and the area of the TV raster covered by each video may be variable.

Simple video insetting could take the form of a split screen (one video source on the left of the TV, another on the right). This is not really insetting, but the technique is the same. Two videos are essentially put through a SPDT switch, with the switch position determining which video is passed. If an electronic switch is used, the timing of the switch position signal will determine which video is presented where on the final TV picture. To be effective, the switching between video should occur at fast rates, typically within a fast sweep resolution element. The following are types of hardware which can be used.

1) <u>Field Effect Transistor (FET) Switches (Figure 5.5-1)</u> - Only one FET is on at a time, passing only one video. It suffers from relatively slow speed (approximately 150 ns) and feed-through caused by the FET capacitance.

2) <u>Dual Video Amplifier (Motorola MC1545) (Figure 5.5-2)</u> - The MC1545 video amplifier has two inputs but only one output. The two inputs are modulated by a gate input arranged so that when the gate is at +1.4 V, input A has full gain while input B has zero gain. When the gate is at 0 V, the opposite is true - full gain on B, zero gain on A. Halfway between 0 and 1.4 V, both videos have the same gain. The inputs are summed internal to the MC1545. The resultant output is then:

$$(\text{Video A}) \times \text{Gain} \frac{(\text{Gate Voltage})}{1.4} +$$

$$(\text{Video B}) \times \text{Gain} \frac{(1.4\text{ V} - \text{Gate Voltage})}{1.4}$$

If the gate voltage swings from 0 to 1.4 V (or vice versa) the MC1545 will act as a switch. Switching time is approximately 10-15 ns.

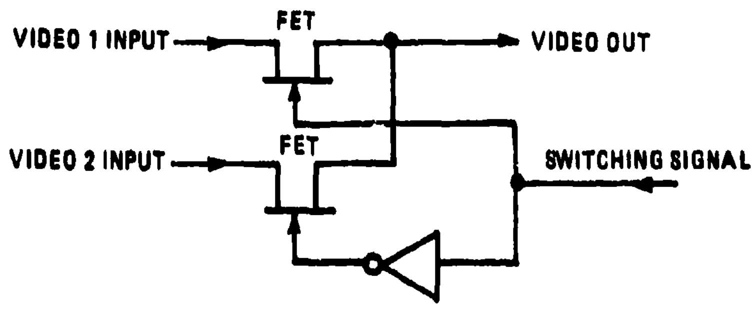

Figure 5.5-1 FET VIDEO SWITCH

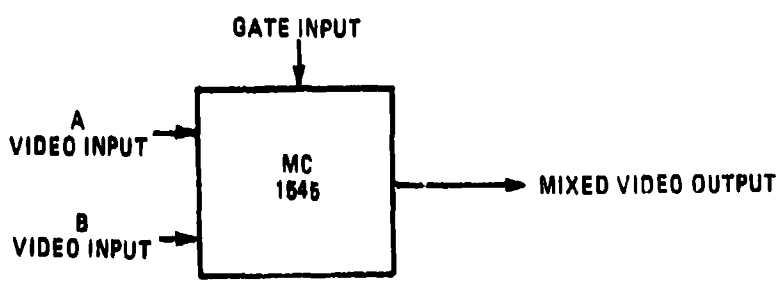

Figure 5.5-2 DUAL VIDEO AMPLIFIER SWITCH

3) Transistor-Diode Gate (Figure 5.5-3) - A transistor and diode circuit can also be used to gate the video. If Gate A is held at ground potential, the video from emitter follower Q1 will pass through CR1 and CR2 to the summing point. If Gate B is at B+, the diodes CR3 and CR4 will be turned off, inhibiting video B. For Gate B at ground and Gate A at B+, the opposite is true. With this circuit if both gates are at ground at the same time, the output will be the summed video rather than inset video. By a judicious choice of components and driving signals, switching can be accomplished again in approximately 10-15 nsec.

4) Chroma-Key Insert (Figure 5.5-4) - The previous discussion was centered around the insertion of one monochrome video signal into another. Chroma-keying is another way of electronically inserting a scene taken against a neutral background into a separately generated background scene. The scene to be televised is arranged against a background which is painted in a saturated color that is absent from the scene itself. The scene is viewed by a television camera, whose output signal is fed to a circuit which derives a binary switching signal whose levels correspond respectively to the scene and the background. A second signal source provides the background signal that is to substitute the flat-color background of the primary scene. The signals of both sources are then fed to an electronic switch circuit which must continuously decide whether the input signal corresponds to the background or to the scene. This requires the availability of a signal which must exceed a certain threshold during the scanning of the background but remain below this threshold during scanning of the scene. It is customary, although not necessary, to employ a saturated blue background because this color can be relatively easily avoided in the scene proper.

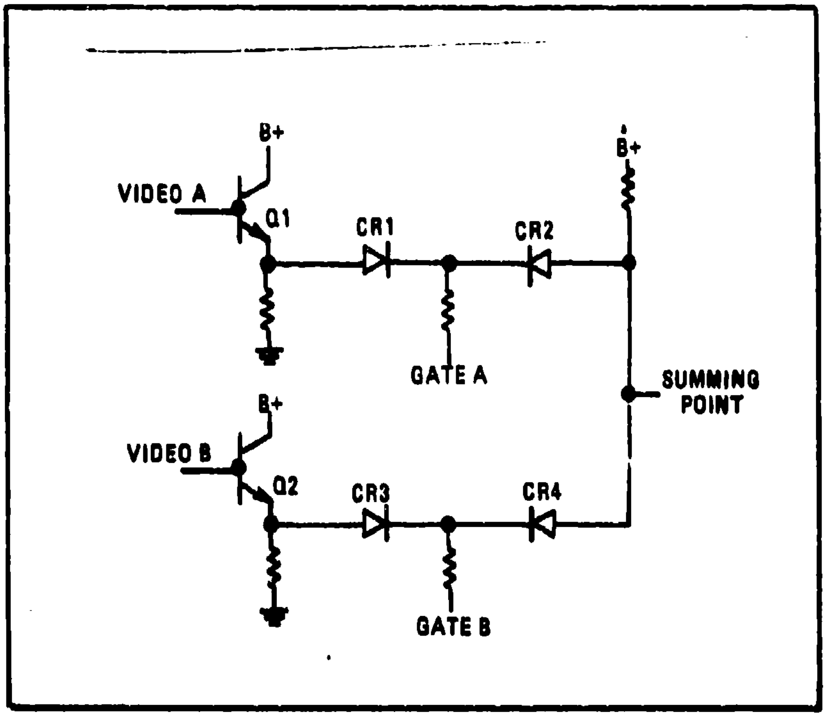

Figure 5.5-3 TRANSISTOR DIODE SWITCH

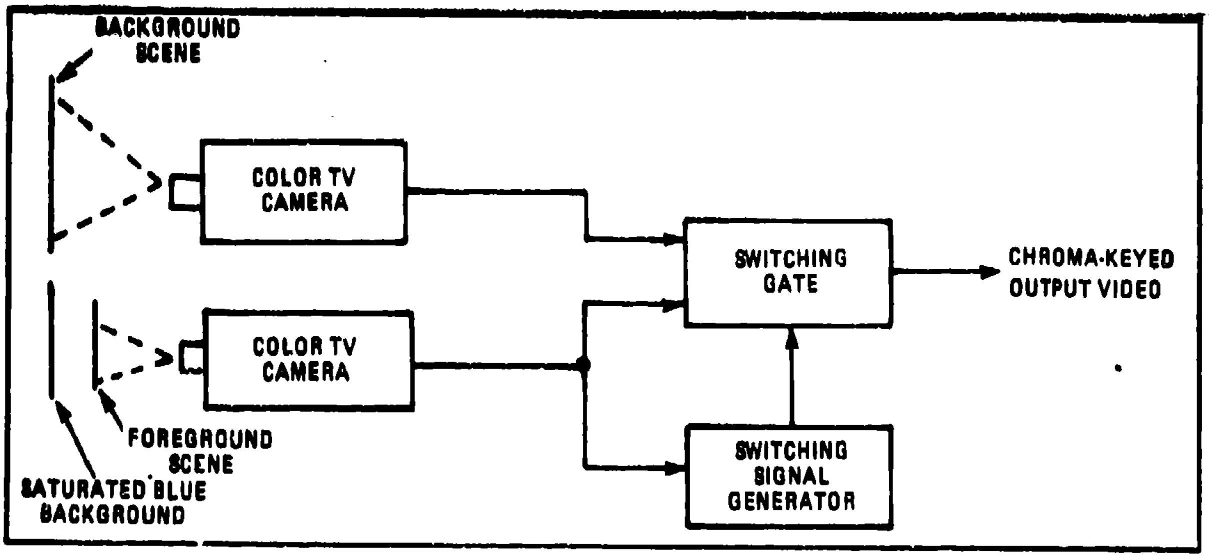

Figure 5.5-4 CHROMA-KEYING BLOCK DIAGRAM

5.6 EXAMPLES OF SENSOR SYSTEM SIMULATION

Description of simulation methodology of a couple of sensor systems will shed light on the methodology of sensor system simulation and integration into visual systems. The LANTIRN simulation at the Cruise Station Design Facility (CSDF) and the B-52 electro-optical viewing system (EVS) simulation are chosen as typical examples.

5.6.1 LANTIRN Mission Simulation

The LANTIRN simulation at CSDF consists of four major building blocks:

1) The A-10 simulator - provides a simulated aircraft base for the LANTIRN Pod.
2) The PDP/11/34 Vector General Symbol generator - provides LANTIRN HUD symbology for the visual display.
3) SMK-23 - provides simulated IR video for the visual display.
4) Visual display - reflects the output of the LANTIRN Pod.

The out-the-window display representing the LANTIRN pod output is a WAC window. Basically a WAC window consists of three parts -- a curved mirror, a beamsplitter, and a CRT (see Figure 5.6.1-1). The imagery on the CRT is direct to the mirror via beamsplitter. The imagery reflects back to the pilot (this gives the apparent "infinity focus" to the eye).

Since the LANTIRN display is 30° wide the CRT raster is compressed to give a 30° picture to the pilot.

FLIR imagery is simulated by using a SMK-23 camera model system. The video is inverted and reflective paints are used for signatures. A zoom lens on the probe permits an easy change from

a normal 60° field of view to the the requested 30°. Since the initial simulated FLIR picture is good, the output is degraded by adding electronically generated "true" fog (this takes into account visibility curves, altitude, pitch, bank, fog density and ceiling, thus coming up with a fair representation of the actual aircraft FLIR.

The HUD symbology is all created by the Vector General in stroke form. The output is then scan converted (by means of a camera looking at a stroke monitor) to 1023-line video and mixed with the FLIR video before it goes to the display CRT.

The airspeed, heading, pitch bar, and velocity vector symbols are driven directly by the aircraft parameter taken from the MK-I. The maverick target, radar altitude, heading bug, TF command, and heading command symbols are driven by a combination of aircraft inputs and equations contained in the PDP-11/34, which also contains an array of points representing the topography on the SMK-23 belts from which radar altitude and T/F commands compute.

As can be noted in Figure 5.6.1-2, the LANTIRN simulation is used as part of a full mission simulation; by adding to the LANTIRN synthetic voice warning inserted into the audio channel, RHAWS video is created by the Vector General and displayed on a cockpit scope and maverick video created by a duplicate SMK-23 and displayed on a cockpit monitor. The audio warning and RHAWS video are matched to threats (hard targets) placed at specific points on the visual scene. The audio and RHAWS video warnings are computer controlled and take into account occulting, altitude, and mission scenario. Thus, if the threats are not protecting the target, they may be visible but are considered not active and no warnings are given.

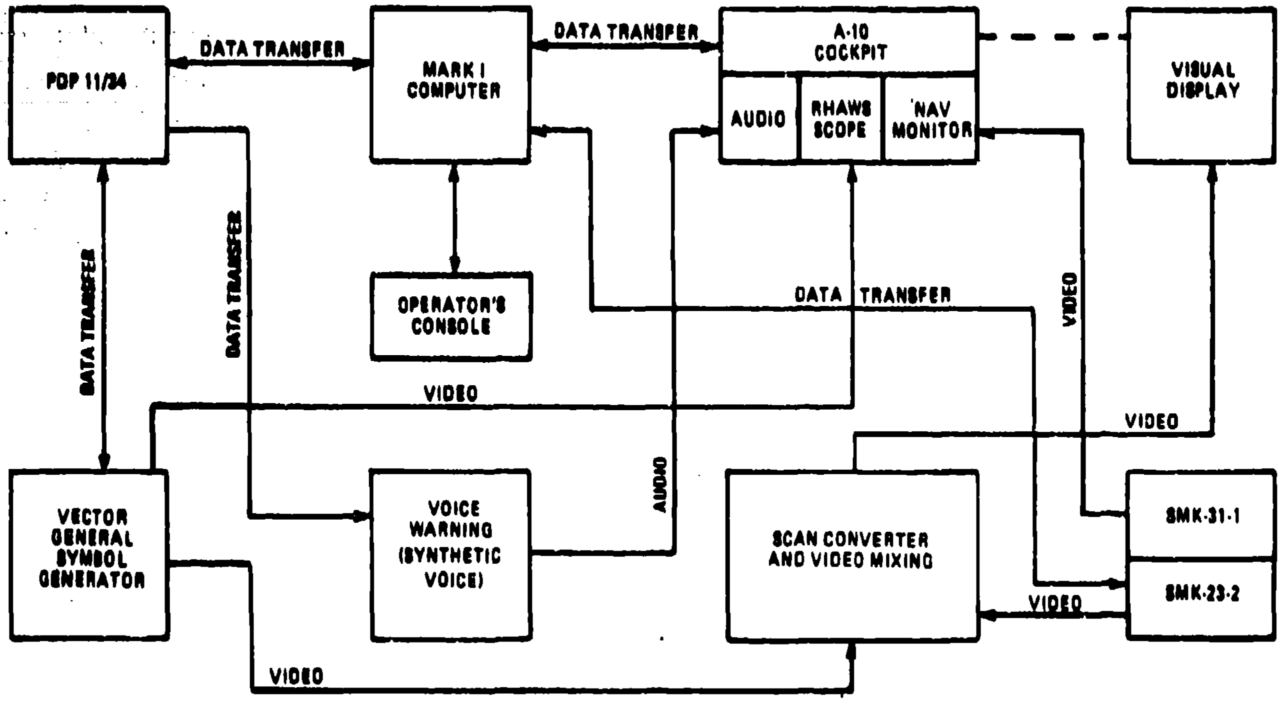

Figure 5.6.1-1 LANTIRN MISSION SIMULATION

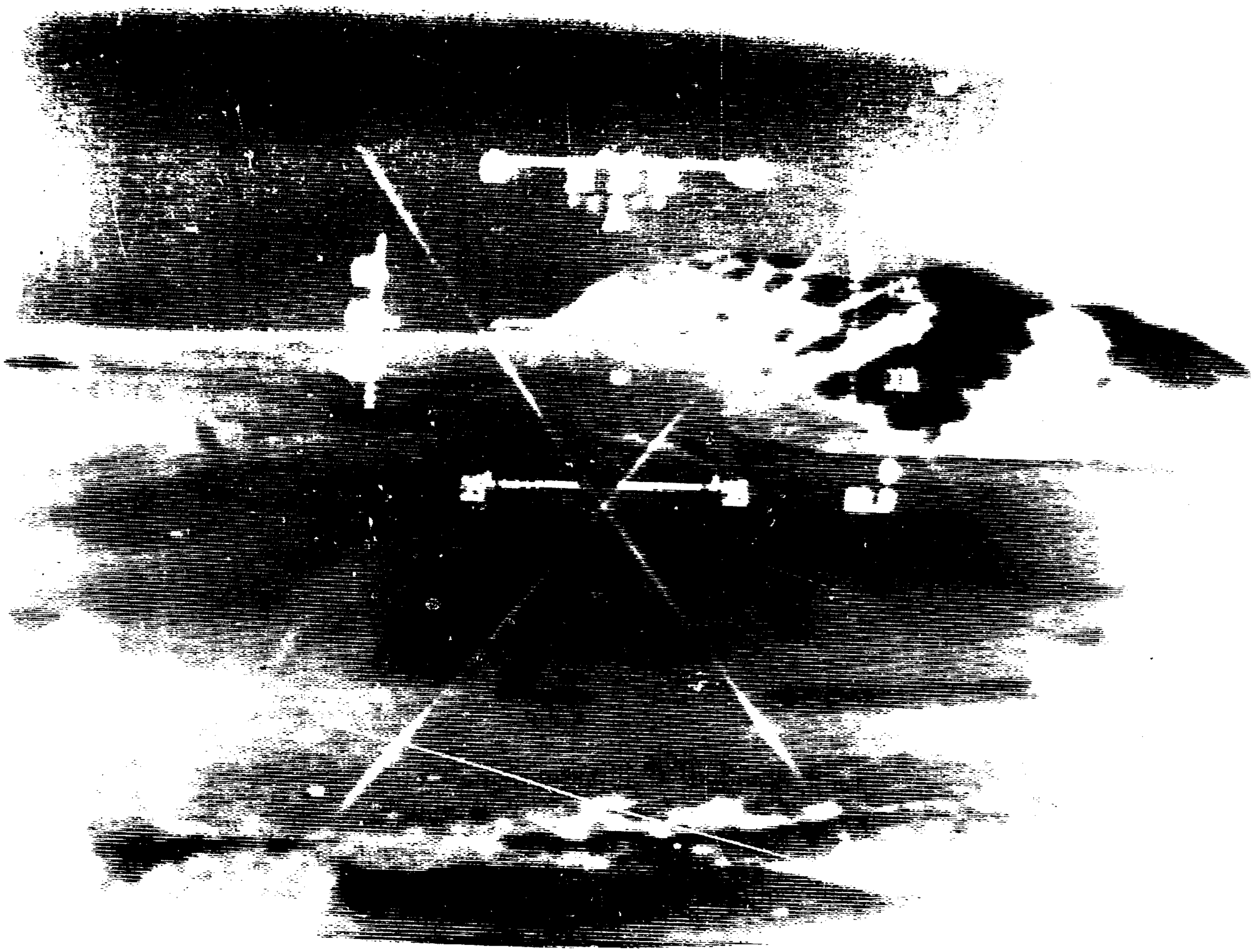

Figure 5.6.1-2 TYPICAL LANTIRN DISPLAY

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5.6.2 B-52 EVS Simulation

Singer proposes to fulfill the requirement for both the B-52 visual and electro-optical viewing system (EVS) simulation through application of a single advanced design DIG system. This image generation system is innovative in the hardware and software techniques used to achieve a system design capable of exceeding the demanding requirements of the specifications. Figure 5.6.2-1 is a diagram of the proposed EVS simulation system and Figure 5.6.2-2 is an artist's concept of imagery and symbology as viewed on an EVS display.

The proposed system will have the capacity to process and display a total of 8000 potentially visible scene edges and lights in a single frame time (1/30 sec). This total number of edges and lights may be shared in any combination between the FLIR and STV displays during simultaneous operation of these sensors in the integrated mode.

The EVS image generation system will employ a three-tier memory hierarchy to permit real-time access to a DDB covering 130,000 nmi^2. The DDB memories are configured to store and access a total of 8 million edges. The top tier of storage is called regional memory and will be composed of two 67-MB moving head disk memories, each covering 65,000 nmi^2. Two disk drives permit maximum flexibility and ease of real-time expansion of the 130,000 nmi^2 gaming area.

The second tier of memory will be composed of rapid-access bulk-storage solid-state memory which holds the data in a 50 nmi radius about the aircraft. This memory is called district memory.

The third level of memory will hold data for a sector 114° wide in front of the aircraft. Although the individual sensors are limited to a maximum horizontal field of 24°, the 114° sector

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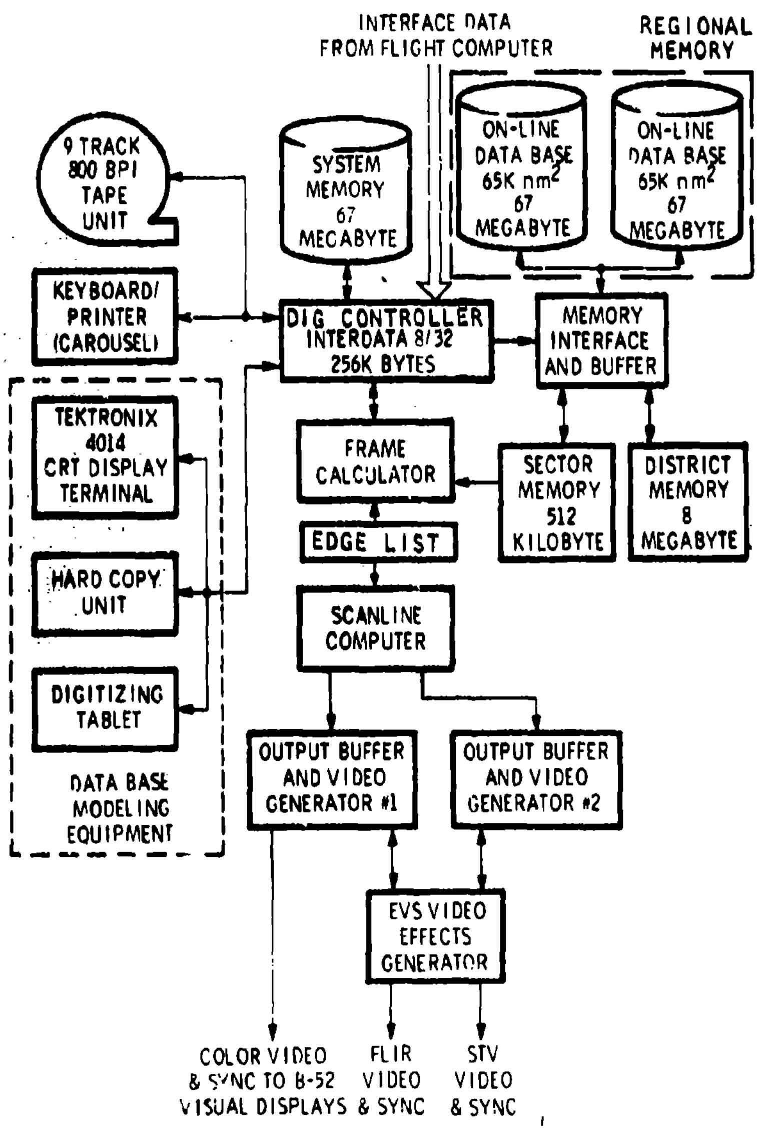

Figure 5.6.2-1 EVS SIMULATION SYSTEM

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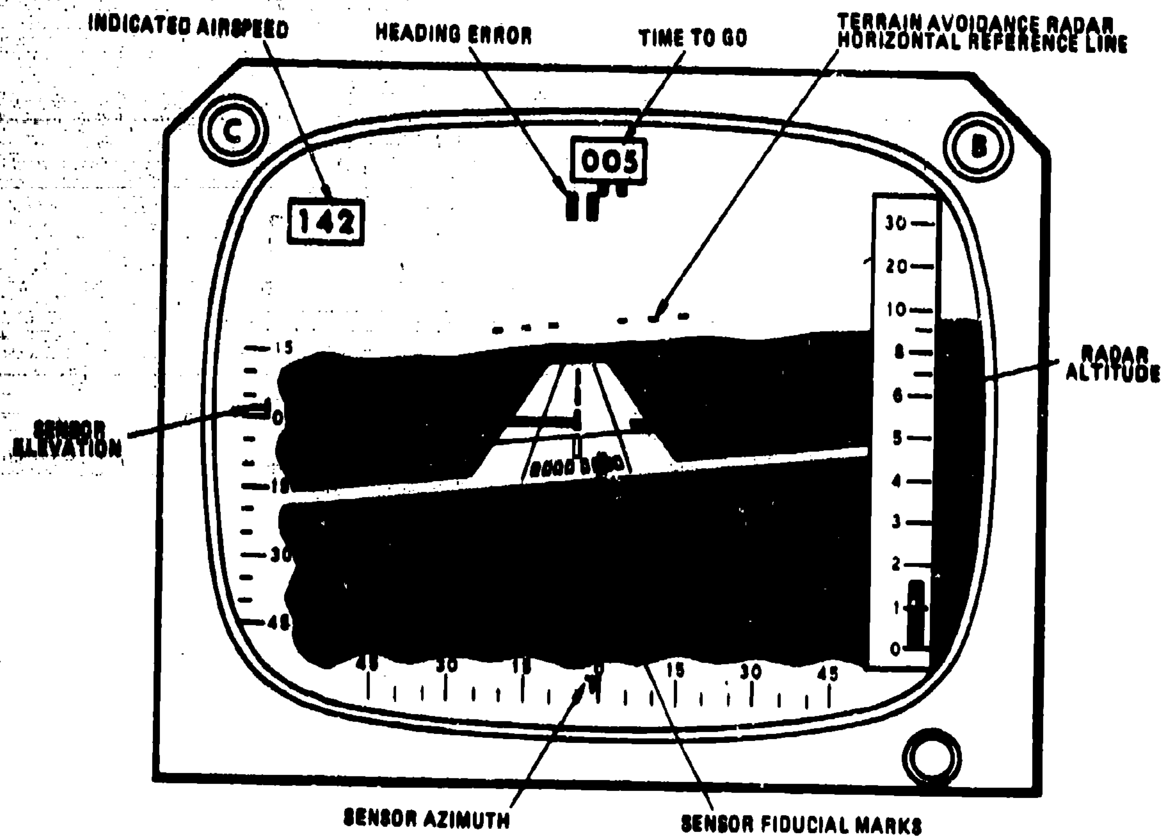

Figure 5.6.2-2 EVS DISPLAY IMAGERY AND SYMBOLOGY

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permits the horizontal scanning of the boresight for the steerable sensors without the appearance of anomalies in the display.

The various DRLMS subsystems and their interrelationships are illustrated in the functional block diagram shown in Figure 5.6.2-3.

The data base for radar will be derived from DMAAC Level I and Level IA data. Portions of the world will be transformed to provide an on-line data base covering at least 600,000 square nmi. This gaming area will be stored on the DRLMS regional memory as an elevation file, a landscape reflectance file, and a reflectance list file. Each file will have multiple resolutions to provide the specified accuracies at the various radar ranges.

As the aircraft maneuvers within the gaming area, district memory will be maintained in real time with a subset of regional memory data that represents the area within the immediate field of view of the radar system. District memory will contain all the elevation, landscape, and reflectance data required within a radar range of 240 nmi for the long-range setting and lesser ranges for the shorter-range settings.

Also, a sector memory will be maintained in real time for each type of data corresponding to the selected radar range and antenna movement.

A graphic representation of radar data flow is illustrated in Figure 5.6.2-4.

The DRLMS on-line DDB will be formed by a digital data base transformation program (DDBTP). In the on-line DDB, terrain elevation data is established using a geodetic grid structure whose highest resolution is 9 arc-sec (approximately 900 ft) between adjacent stored elevation values. Intermediate elevation values

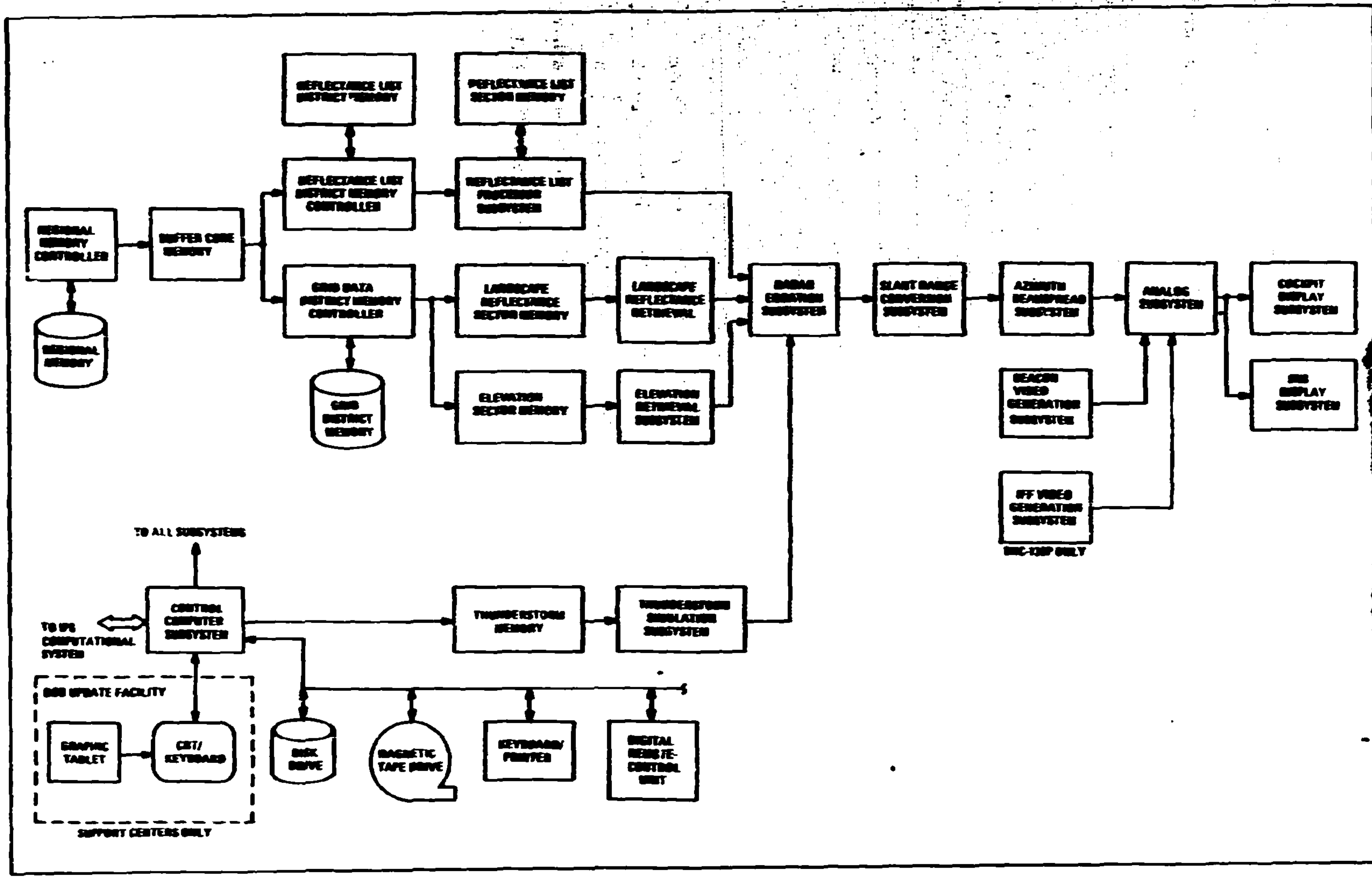

Figure 5.6.2-3 DRLMS SYSTEM BLOCK DIAGRAM

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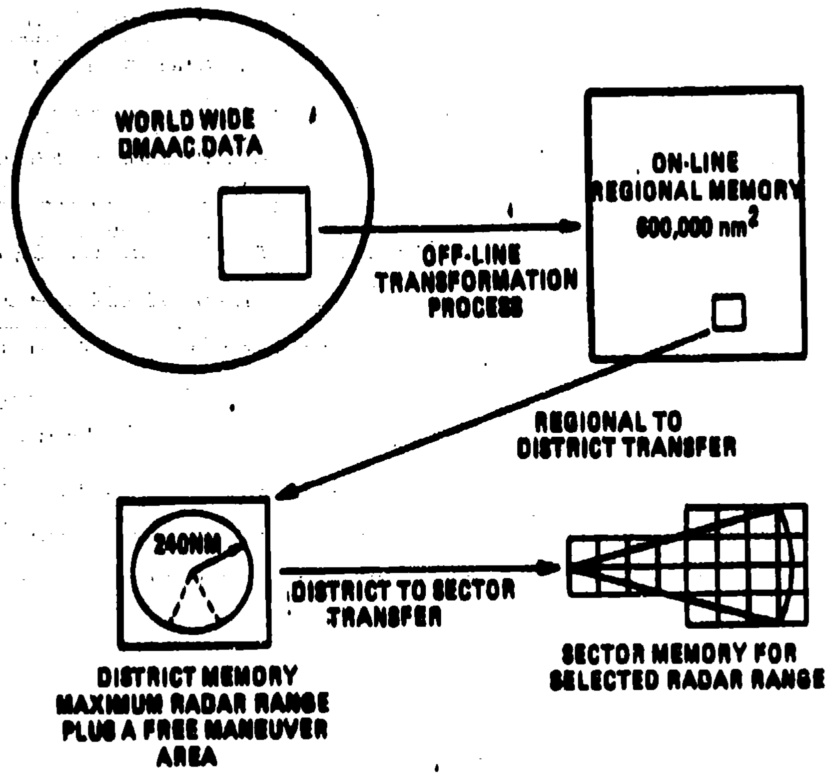

Figure 5.6.2-4 RADAR DATA FLOW

[redacted]

will be determined within the DRLMS by a system of weighted parabolic interpolation in the elevation retrieval process. Radar-significant landscape features are established using a geodetic grid structure with increments as small as 1.5 arc-sec (approximately 150 ft). The stored data volume will be reduced by run-length compression techniques.

A data file is made up of an uncompressed list-structured string of points, each point representing a rectangle of variable length/width ratio. Each point can be rotated, and has a cultural elevation, a low-level special-effects flag, and a 4-bit reflectivity code. Positional resolution of features in this file is 0.3 arc-sec. Should the user wish the accuracy of a selected landscape feature to be better than depicted initially in the landscape data file, the list reflectance file can be used to augment the basic landscape information. This alliance of grid and list encodement and processing methods allows for high density of radar-significant data without requiring similar amounts of digital data in areas having few radar-significant features. Furthermore, it permits the realistic simulation of landmass returns without the display of undesirable synthetic or cartoon-like anomalies characteristic of a data base consisting of planar or faceted elements.

The on-line DDB is stored in a memory hierarchy as illustrated in Figure 5.6.2-5. As data progresses from left to right, data rates increase while data volume decreases. As a result, memories are selected at each stage to provide the best tradeoff among volume, speed, and cost.

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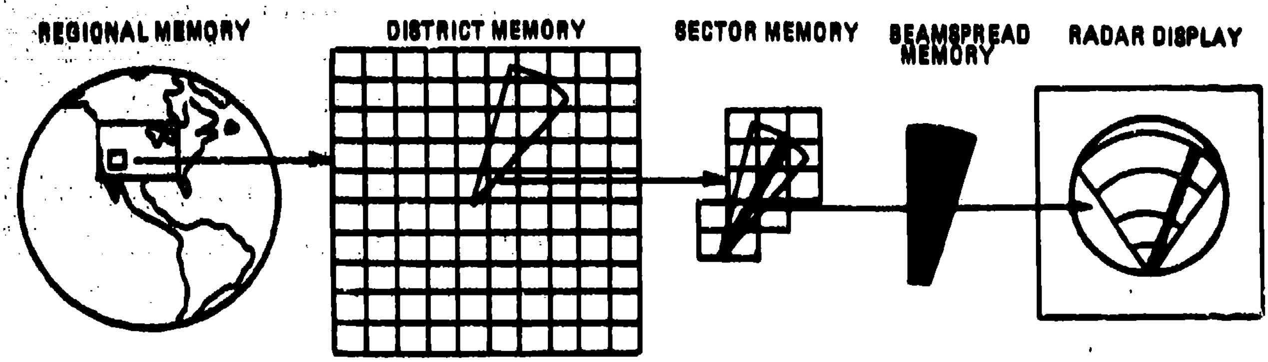

Figure 5.6.2-5 DRLMS MEMORY HIERARCHY

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6.0. CONCLUSIONS

6.1 GENERAL

This study has analyzed FDL's sensor simulation requirements, typical sensor characteristics, and simulation technologies applicable to the sensor simulation problem. It is apparent that no off-the-shelf solution exists for the total problem and consequently some new equipment will have to be purchased or possibly even developed. This is not an entirely unexpected result since the simulation industry has only recently been driven toward solving the problems of sensor simulation and therefore solutions are still in infancy stage. We can expect that as sensor simulation matures, its capabilities and characteristics will be developed and refined in response to specific requirements.

In this light, this report has demonstrated three important facts. First, sensor simulation has emerged and can be expected to develop as a distinct simulation technology. Second, FDL must develop sensor simulation capabilities expeditiously in order to be responsive to sensor related advancements which are emerging in flight control technology. Third, FDL must continue to develop its capabilities in parallel with the growth of simulation technology. The practice of procuring only proven equipment has obvious merit, but with its chartered task of analyzing crew workloads in mission-associated tasks using advanced sensor equipment and developing control systems and utilization techniques, FDL cannot afford to wait until the simulation technology fully matures.

Beyond the fact that FDL must assume a degree of risk, the future for sensor simulation and correspondingly FDL's ability to develop advanced sensor simulation capabilities appears extremely promising. This optimism is derived from the knowledge that virtually every basic aspect of sensor simulation can, to varying degrees, be feasibly produced by extracting capabilities of

existing technologies. The basic problems to be overcome are putting these capabilities together and expanding on their content (i.e., data base expansion and sensor signatures). FDL may well be one of the first to develop a full sensor augmented mission capability for an advanced fighter aircraft. However, FDL's initial development will be closely followed if not paralleled by similar development in the training sector as the U.S. Air Force Simulator Procurement Office (SPO) seeks to upgrade its simulators with the sensor capabilities being implemented in the parent aircraft. One such possibility is the incorporation of a LANTIRN simulation in the F-16 Tactical Flight Simulator. Other sensor systems which need to be simulated are TADS (Target Acquisition Designation Sight) and PNVS (Pilot Night Vision Sensor).

6.2 SENSOR TRENDS AND SIMULATION TRENDS

The basic relevant segments of sensor augmented missions have been shown to be penetration, target acquisition and identification, and weapons delivery. The sensor augmentation for high-speed, low-altitude penetration is precision navigation including obstacle avoidance, location identification, and electronic warfare activity. TA/TF simulations were accomplished in the early 1970's (in the F-111 ARLMS). DRLMS is well proven for navigational real beam mapping. Increased data base resolution, modified access hardware, and possibly the incorporation of scan conversion memory should facilitate DRLMS expansion for DBS and SAR realizations. Also, by the nature of its data base, DRLMS is inherently adaptable to TA/TF.

Electronic warfare has been simulated to some very elaborate levels. There appear to be no technical problems associated with applying known EW simulation techniques to sensor augmented missions. Initial sensor target acquisition is usually accomplished by radar at ranges greater than practical for E-O acquisition. Air and ground targets accompany most DRLMS configuration. At

closer ranges, handoff is made to E-O sensors for target identification and subsequent weapons delivery. CMS, film source, and DIG targets of E-O quality have been generated in various training simulators. Providing the proper IR signatures appears to be predominantly a problem of determining what the signature should be. Various methods exist for inserting target presentations into separate sourced background video. When automatic target identification becomes a reality, the simulation problem will be easier since the computer will always know the identity of each target. Both natural and tactical environmental factors are included in most current tactical visual systems.

In reality, when simulating sensor augmented missions, it will be the correlated visual presentation that will present the more dramatic challenge in terms of existing technologies. This report has noted the drawbacks of both DIG's and CMS's when used for low-altitude missions. Distance and speed cuing do not affect sensor simulation, however, since by virtue of their two-dimensional displays, sensor presentations do not facilitate such cuing.

Earlier sections of this study discussed various sensors and their characteristics. It was mentioned that sensor technology (especially radar) was mature in principle and that major advancements will come in areas of signal and video processing. The trends and goals are to carry computer aided processing to a point where only symbolic data is presented to the crew in an MFD. This is an obvious result of ongoing efforts to reduce crew workloads and these efforts, in turn, will have a significant effect on simulation hardware.

As the need for real-world video is diminished, the computer image generator becomes more prominent and the film, tape, disk and camera-model systems become less significant. In the short term, this may have little impact, but in the long term, as these

processing techniques are implemented in operational hardware, the simulation facility will have to respond through the acquisition of CIG equipment.

These facts must be considered along with trends in simulation technology in planning facility expansions. The CIG, although it is a rather new addition to simulation technology, has proven its capabilities and is unsurpassed in some areas such as flexibility. The bulk of current research and development budgets in the simulation industry are directed toward improving this technology. It follows, that although significant limitations still exist in generating and using the computer generated images, these problems will be solved and that any long term facility expansions must seriously consider CIG as a primary image source.

6.3 SUMMARY OF IMAGE GENERATOR CHARACTERISTICS

The salient characteristics of the various sensors and the different image generation forms are summarized in Tables 6.3-1 through 6.3-3. These tables provide at a glance a comparison of what is required for simulation of the sensors and what performance parameters can be realized by each type of image source.

6.3.1 Camera Model

Most LLLTV and FLIR systems have pictorial content compatible with camera model boards. However, most sensor systems have relatively narrow FOV's, down to a fraction of a degree. These FOV's view are not practical to simulate with optical probes due to diffraction limitations and depth of field requirements. Thus CMS's systems will only be applicable for a limited number of E-O sensor devices, or may be applicable with restricted performance capability. A second restriction of CMS's lies in their relatively small gaming area. This imposes a limitation on the type and extent of mission simulation in which they can provide a useful output for mission analysis.

Table 6.3-1 IR, FLIR, IIR

PERFORMANCE PARAMETER	REQUIREMENTS	IMAGE GENERATOR: CIG	CAMERA-MODEL 1500:1	CAMERA-MODEL 5000:1	FILM	VIDEO DISK/TAPE
1. Sensor characteristic	IR	Good	Good-special model	Good-special model	Fair - distortion	Fair - distortion
2. Field of view	1/2 by 16° 3 by 4° 1.5 by 2°	Match all	Difficult to switch FOV	Same as 1500:1	Match all	Match all
3. Resolution	300-600 lines	Match	Difficult - limits many parameters	Same as 1500:1	Requires special picture for very small FOV	Same as film
4. Depth of field	Infinite	Match	Poor	Very poor	Match	Match
5. Detail	Resolution limited	Fair	Matches in area in focus	Fair - model dependent poor out of focus	Match	Match
6. Gaming area	No limit	Unlimited	Limited to board - poor	Limited to board - fair	Limited to storage	Limited to storage
7. Flexibility	High	Good - possible to change data base	Difficult	Difficult	Requires new film	Requires new processed data
8. Moving models	Required	Good	Difficult - Requires video insertion, may appear unrealistic		Same as CM	Same as CM
9. Target generation	Inherent	Good	Requires external generation equipment			

Table 6.3-1 IR, FLIR, IIR (Cont'd)

PERFORMANCE PARAMETER	REQUIREMENTS	IMAGE GENERATOR				
		CIG	CAMERA-MODEL 1500:1	CAMERA-MODEL 5000:1	FILM	VIDEO DISK/TAPE
10. Color	Not yet but could be required for displays	As required	As required	As required	As required	As required
11. Compatible with other sensors and out-the-window	Required	Excellent	Possible with different models for FOV considerations		Good - more equipment	Good - more equipment
12. Correlation with other sensors and out-the-window	Required	Excellent - 1 pixel	Fair	Fair	Good	Good - fair
13. Accuracy	Required	Excellent - 1 pixel	Fair	Fair	Fair	Fair
14. Ordinance depiction	Inherent	Excellent	Fair	Fair	Fair	Fair
15. Minimum altitude (terrain)	Aircraft	Unlimited	Limited by aperature - fair	Limited by aperature - poor	1000 ft	1000 ft
16. Maneuver-ability	Unlimited	Unlimited	Unlimited	Unlimited	Very poor	Fair

Table 6.3-2 TELEVISION

PERFORMANCE PARAMETER	REQUIREMENTS	IMAGE GENERATOR: CIG	CAMERA-MODEL 1500:1	CAMERA-MODEL 5000:1	FILM	VIDEO DISK/TAPE
1. Sensor characteristic	Television	Good	Good	Good	Fair - distorted	Fair - distorted
2. Field of view	15 by 20° 5° by 5° 5 by 6.6 1.5° by 2° 75 by 1° 5° by 0.66°	Matches all rqmts	Difficult to switch-requires Special probe	Same as 1500:1	Match all	Match all
3. Resolution	300-800 lines	Matches rqmt	Difficult - limits many parameters	Same as 1500:1	Requires special pictures for narrow field	Same as film
4. Depth of field	Infinite	Matches rqmt	Fair for wider, poor for narrow angle	Poor to very poor	Matches rqmt	Matches rqmt
5. Detail	Resolution limited	Fair	Matches rqmt for area in focus	Same as 1500:1	Matches rqmt	Matches rqmt
6. Gaming area	No limit	Large - no limit	Limited	Limited	Limited to storage	Limited to storage
7. Flexibility	High	Good - data base can be changed	Difficult	Difficult	Requires new film	Requires new processed data
8. Moving models	Required	Good	Difficult - Requires video insertion, may appear unrealistic		Same as CM	Same as CM

Table 6.3-2 TELEVISION (Cont'd)

PERFORMANCE PARAMETER	REQUIREMENTS	IMAGE GENERATOR: CIG	CAMERA-MODEL 1500:1	CAMERA-MODEL 5000:1	FILM	VIDEO DISK/TAPE
9. Target generation	Inherent	Good	Requires external generation equipment		Same as CM	Same as CM
10. Color	Not yet, but could have color	Good	Good	Good	Good	Good
11. Compatible with out-the-window	Required	Excellent	Fair	Fair	Fair	Good - Fair
12. Correlation with other sensors and out-the-window	Required	Excellent	Fair	Fair	Fair	Fair
13. Accuracy	Inherent - high	Excellent	Fair	Fair	Fair	Fair
14. Ordinance depiction	Inherent	Good	Fair	Fair	Fair	Fair
15. Minimum altitude (terrain)	Aircraft	Unlimited	Limited by probe clearance = 10 ft	Limited by probe clearance = 35 ft	≈1000 ft	≈1000 ft
16. Maneuverability	Unlimited	Unlimited	Unlimited within model area	Unlimited within model area	Very poor	Fair

Table 6.3-3 RADAR

PERFORMANCE PARAMETERS	SENSOR PERFORMANCE	SIMULATOR CAPABILITY ANALOG	SIMULATOR CAPABILITY DIGITAL
Fidelity of azimuth	Excellent	Inadequate	Realistic
Fidelity of vertical antenna	Excellent	Good	Excellent
Fidelity of pulse stretching	Excellent	None	Excellent
Targets	Required	None	Yes
Beacons	Required	None	Yes
Jammers	Required	?	Yes
Fidelity of weather	Unlimited	?	Excellent
Weather area	Unlimited	?	50K nmi^2 area
Weather levels	Unlimited	?	7
Weather shapes and structure	Unlimited	?	Unlimited
Expandable for			
Air target occult	Required	?	Yes
Jammer occult	Required	?	Yes
Longer ranges	Required	?	Yes
Worldwide flight	Required	?	Yes
Seasonal effects	Unlimited	?	Excellent
Extensive diagnostics	N/A	?	All
Commonality with B-52/ C-130	N/A	?	90%
Interface	N/A	?	Computer to computer
Interface to indicator	Video	?	Video

Table 6.3-3 RADAR (Cont'd)

PERFORMANCE PARAMETERS	SENSOR PERFORMANCE	SIMULATOR CAPABILITY ANALOG	DIGITAL
Positional accuracy	To resolution limit	>1000 ft	250 ft
Resolution	30-300 ft	500	<250 ft
Pos drift	None	?	None
Data base change time	N/A	>1 hr (need recalibration)	<5 min
Mission area	Unlimited	1250 by 1250 nml	Unlimited
Retrieval errors @ 80 nml	N/A	4 nml	0.1%
Cultural levels	Noise limited	7	16
Elevation range	Aircraft limited	Sea Level -12,800 ft	-2,000 ft 30,000 ft
Elevation steps	Unlimited	56	>4,096
Elevation step resolution		100 ft min 1,000 ft max	2 ft
Data base update on-site	N/A	No	Yes
Data base quality	N/A	Not Representative	Best available if DMAAC used
Future and advanced data bases	N/A	None	As Available from DMAAC
Resolution expansion possible to 100 ft	10 ft	No	Yes
Resolution and feature quality expansion to 35 ft	10 ft	No	Yes
Fidelity of aspect	Excellent	?	Excellent
Fidelity of low-level Presentation	Excellent	?	Excellent
Fidelity of shadow	Excellent	?	Excellent
Fidelity of slant range	Excellent	Good	Excellent

CMS's deliver a picture which contains a high degree of realism. They present the closest example to real-world conditions of any visual system, having unlimited flight patterns (as long as the pilot stays on the model board) and good detail rendition. FDL currently has two CMS's available. One is a 5000:1 scale model covering 12.3 by 37.8 nmi in area and one is a 1500:1 scale model covering 3.7 by 11.7 nmi. The two units are identical physically and both use color cameras. The high detail (1500:1) model has been color-coded to allow a simulation of FLIR.

However, CMS's also have many limitations, the most obvious being the limited gaming area, bounded by the physical size of the modelboard at a given scale. Other limitations include:

1) The limited minimum altitude which can be flown without risking physical collision between the probe and the model.

2) The limited resolution and depth of field which can be provided.

3) Inflexibility in making data base (model) changes.

4) FOV limitations for visual, out-the-window scenes.

5) When correlation between two separate camera model scenes is required, positional servo inaccuracies also become significant because they are magnified by the scale of the models.

Consideration of these limitations and capabilities as they apply to the current problem of sensor simulation and the systems available at FDL is provided below.

Although the gaming area of the camera model is limited, it is possible to program flight corridors on the model which will effectively extend the gaming area several times. While this will not entirely alleviate the problem it would provide some relief. Looking to the future, the camera model could be joined with a CIG which provides extended gaming area runs while the model supplies high detail in a specific mission task terminating area.

The CMS's at FDL provide a 60° diagonal FOV. Although this represents the normal field of view for CMS's it is somewhat restrictive for many out-the-window visual requirements. This could be improved on the existing systems only through an exchange of probes.

On the other hand, most of the E-O sensors being examined have very small FOV's - in the order of 20° maximum down to a fraction of a degree. Reducing the FOV of the probe presents no technical problem. However, the system resolution is already limited primarily by the diffraction limiting effect of the probe aperture. Thus, reducing the FOV will not be accompanied by a corresponding desired increase in angular resolution, although some increase would be realized through the associated increased angular resolution capability of the TV camera and display. For example, if the current probe image were to be reformatted to simulate a 3° FOV only about 100 (or less) resolution elements would appear across the image, making it appear grossly out of focus. The probe resolution could be increased only by increasing the pupil size.

This tactic, however, also results in a reduced depth of field for the probe in inverse proportion to the aperture diameter increase. Further, enlarging the pupil also enlarges the optical elements of the probe and could very likely constrain the near approach distance of the probe to the model even more than it is now. Thus, resolution, either in absolute terms or in depth of

field, represents the most significant deterrent to the application of CMS to sensor simulation because one limiting parameter can be improved only at the expense of deteriorating the other. Figure 6.3.1-1 illustrates the interactive effects of pupil diameter and resolution, depth of field, and model approach distance.

Finally, there is the factor of image correlation in those cases where two separate CMS's must be employed to provide registered images on a common display or contiguous set of displays. Such a case could arise if one model were used to provide out-the-window imagery and a second to provide FLIR imagery on a HUD, for example. Although it is possible to achieve good correlation with two carefully matched models and very careful calibration of position and attitude servos with position feedback provisions to the computer, separate processing of a common video signal is perhaps more practical. Such a capability would be provided by a DAIS unit (McCormick et al, 1979), although with some compromises required on the FLIR resolution and IR signature representation.

Therefore, it seems fairly obvious from the above discussion that the CMS of very limited utility in satisfying the requirements of sensor simulation. But with some modification, replacement, and additions to the existing systems at FDL some useful interim level of simulation could be realized. By the use of a more advanced camera model system similar to the Orbiter Aero-flight Simulator (OAS) used at NASA's Mission Simulation facility at Johnson Space Center, Houston, Texas, together with a DAIS or other special video processing unit, many of the desired performance parameters can be improved over that presently available. For example, some of the characteristic OAS performance parameters of interest here include:

1) Wide (120°H by 40°V) FOV imaged onto three overlapping color camera channels of 46°H by 40°V each

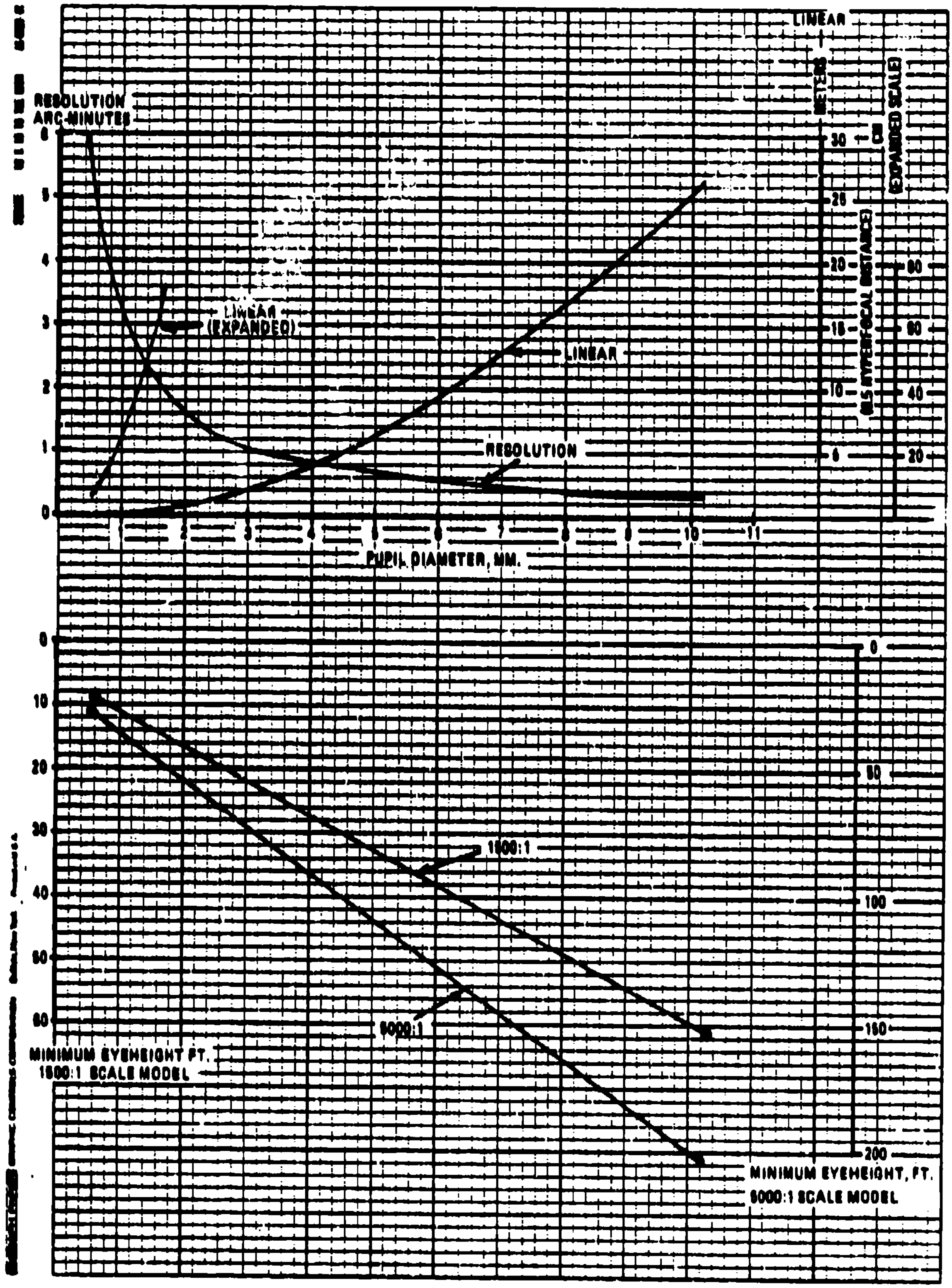

Figure 6.3.1-1 EFFECTS OF PROBE APERTURE SIZE

2) 1.0 mm probe pupil diameter with a minimum eyeheight of 4.2 mm (times model scale factor)

3) Scheimpflug correction for low-altitude flight

4) Resolution 9 arc-min per line pair with modulation in excess of 10% in the corners of the field, with or without full tilt correction

5) Probe attitude and gantry position feedback signals for closed loop control through the computer

6) Full pitch capability from +30° to -88°. This CMS has been replaced in the operational simulator with a CIG, and it may therefore be available to FDL on a surplus basis

Attaining any one or all of these characteristics would require replacement of the existing probes with new units. The new probe should have an enlarged pupil aperture to increase resolution with the aperture being adjustable for different FOV's to be simulated, either a zoom mechanism or provision for inserting auxiliary lenses for various fixed magnifications, plus servo feedback for computer interfacing to increase the accuracy of line-of-sight positioning. An increased FOV for out-the-window viewing would be highly desirable if the display could be expanded accordingly.

6.3.2 <u>Film, Videotape, or Disk Systems</u>

While film and videodisk systems have limitations in altitude variation, maneuverability, and image behavior that could limit these simulation and training applications, their use in FDL research may prove cost-effective. The systems have good static image quality and high detail content. They would be useful for

high- and middle-altitude flights, but could not be used for TF applications. Most mission applications would require maintaining a rather narrow flight envelope and heading constraint to avoid overextending the data base storage capability.

The addition of new flight areas requires extensive planning. The cost of these systems is moderate. Since each picture contains a limited viewing window, practical constraints on storage will limit the allowable flight envelope, including aircraft attitudes, to maintain the out-of-window scene.

A typical videodisk or videotape system is shown in Figure 6.3.2-1. The system operates as described in Section 5.1.2. The pictures have been stored on the video recording medium in sections. The sections are recalled and placed upon the scan converter. The scan converter then translates the picture according to the flight path using perspective transformation algorithms based upon the position and attitude of the photograph and the position and attitude of the aircraft. These transformations have been accomplished in the past and are not considered to be a new development.

These systems, as well as film systems, have a distinct advantage of being easily adaptable to any sensor signature or spectrum anlyses. Either multiple pictures can be taken using the desired spectra, or the picture can be reanalyzed with new information added. The videodisk can be quickly changed (even though the production of a new disk can be somewhat costly), and disks can be stored without undue space being occupied. The information is of the real-world, and any location in the world that can be obtained using photographic techniques can be simulated.

Maneuverability is somewhat limited by data storage considerations, for even with video disk or tape technology there is only a limited amount of data available per disk. Film techniques are of limited value due to the lack of aircraft manueverability.

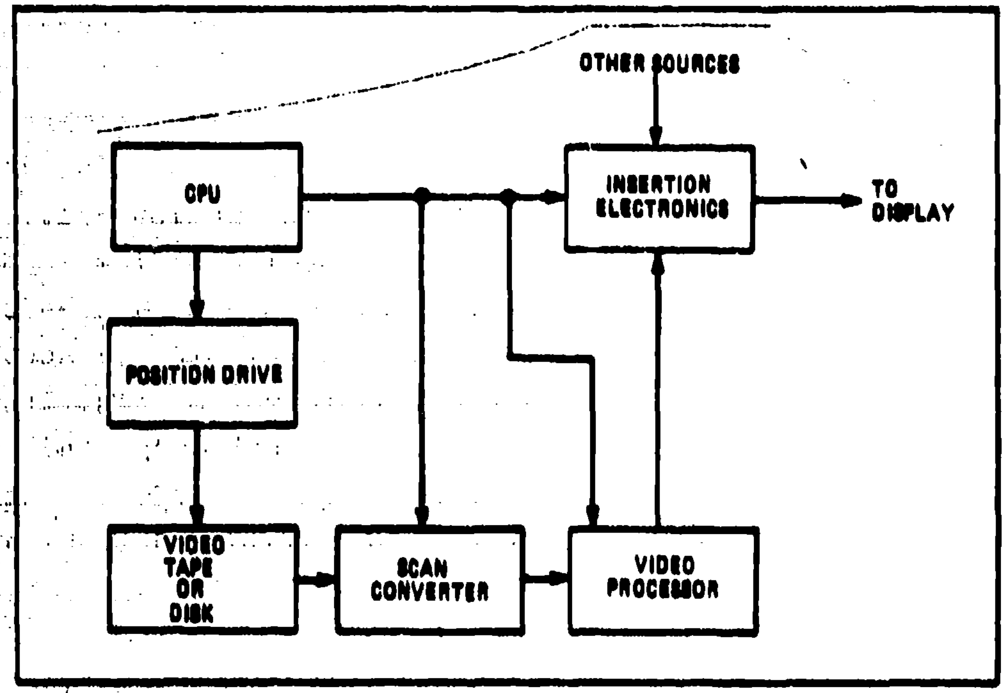

Figure 6.3.2-1 TYPICAL VIDEO TAPE OR DISK SYSTEM (REAL-TIME DISPLAY)

It would seem as if video techniques would be the answer to presenting a wide range of sensor data. However, there are many limitations still present with any such system. First of all, there is a limited amount of pictures that can be stored on a standard 1/2 hour disk. Since each picture could consist of as many as 60 television frames, or two seconds worth of storage, a disk would only contain 900 pictures, a decidedly limited data base. Multiple disk systems could be used to overcome this problem.

Secondly, each picture is "flown" through for awhile before changing unlike the normal movie frame, where each frame is fresh and corresponds to the velocity of the aircraft. Thus, the absolute perspective of an object remains static during this time. The sense of motion is obtained by "zooming" and maneuvering the scan converter raster in a mode that portrays the proper image size to the trainee and maintains the proper perspective. When the image is switched to another picture, there will be a discontinuity in certain objects due to a sudden perspective shift, and probably a slight position shift due to both perspective changes and alignment error. While some of these anomalies may be eased by various techniques to prevent flicker, there will be a change in the image quality at this time. Obviously, one way to reduce some of these errors is to have more pictures, which cuts down the gaming area per disk and increases data base costs.

The third limitation is caused by the perspective transformations available to modify the picture. There is no knowledge of the vertical content of the pictures - hills, trees, towers, mountains, etc. The perspective transform is based upon a "flat earth" concept having no vertical relief. Even though all flat area will be shifted and transformed in perspective, all vertical objects will also be skewed, tilted, and zoomed, causing them to appear distorted.

The perspective transform has still another limitation in that it forms a mirror image around the horizon line. Normally, this forms no problem since the upper part is cut off electronically and replaced by sky. However, if any object begins to approach the horizon or lie above the nominal horizon line, as would be the case when the picture is taken at low altitudes, a mirror distortion would appear and cause disorientation. Since the perspective algorithms are centered at the horizon line, an object which appears above the nominal horizon line (hills or mountains, etc.) cannot be made to drop below the horizon line as would be the case as the aircraft began to gain altitude to avoid the obstruction. The object appears to grow as the aircraft climbs, or shrink in altitude as the aircraft lowers. The result is a startling loss of orientation for the viewer. Thus, these systems are not compatible for simulating low level terrain following tactics.

The pictures must be taken using a stabilized platform, usually mounted in a cradle in a helicopter. The pictures must then be carefully processed to assure smooth transition from one frame to another. Thus the addition of new gaming areas is not a simple or a quick turn-around task, although it is possibly simpler than making a new model for a CMS or making a new CIG data base.

The videodisk and tape systems have the advantage over CIG systems of giving good detail and resolution in the picture. However, many limitations exist in gaming area, maneuverability, altitude simulation, and flight realism. These limitations, while raising serious objections for some training missions, may be adequate for FDL use, where pilot training is not the goal. Thus, the videodisk and tape system may prove to be a lower cost alternative to the CIG system if these limitations are kept in mind.

The videodisk and tape systems may be combined with CMS or CIG approaches. The camera model can be photographed as the

model, even though care must be taken to assure adequate resolution and depth of field, which can be difficult due to the closeness of the camera to the modelboard.

Videodisk systems as described may be adequate for sensor displays that are black and white. While they may be stored as color information using standard commercial color encoding, their conversion to display format and perspective transformation requires scan conversion. Due to the non-linear nature inherent in scan conversion, the scan conversion technique requires one converter for each color. Thus if a color display is desired, three scan converters must be used.

The use of video disk systems for out-the-window displays is limited by all the criteria listed.

6.3.3 CIG

Modern raster CIG systems provide 6,000 - 8,000 edges with at least 256 levels of occulting. All manufacturers of CIG equipment use a common system design but are not board-for-board interchangeable. Current CIG systems are being gradually extended in capability, adding texture and other features that will extend the apparent object density of the picture. CIG is the most versatile of the image generation techniques, adaptable for simultaneous generation of out-the-window scenes of any FOV, and any type of sensor picture.

Section 5.1.5 discusses the use of CIG systems for sensor simulation in detail. All modern CIG systems make use of a common design approach, and there seems little chance of any major breakthrough leading to a new system approach over the next five years. There will be new generations of CIG announced, but these will primarily be undertaken to reduce hardware complexity, ease growth capability, and increase scene content.

CIG has the inherent capability of being adaptable to virtually any type of display image, as long as it is raster scanned. The pictorial results are controlled primarily by the data base control, even though some features caused by spectral content (e.g., IR images) are better controlled by some hardware modifications.

Many types of sensors have been simulated by CIG in the course of the development of the various types of mission systems including TF/TA. Thus, the background necessary to successfully design a useful CIG system for FDL is present. These systems have been mixed from the same CIG system, including out-the-window color scenes, FLIR, and LLLTV.

CIG, since it is determined by computational means, has no comparable problematic resolution limit and depth of field, other than that defined by the arithmetic data base. Thus there is no inherent limit on simulating any desired field of view for sensors. The problem present in CIG's is the difficulty of providing detail under high magnification. The problem can be eased somewhat by judicious planning of the data base content, and using multiple data bases, one for each type of display. Moving targets are relatively easy (even though the movement is presently somewhat restricted) and they are realistically occulted. Target location is well-known, and the strikes and destruction of the target are quickly determined and depicted. Since the CIG imagery is stored in computational form, it is possible to add special features and effects not possible with camera model depictions. Image degradation, coma, and flare can be provided either with current equipment or in the near future. This capability should be especially useful to FDL, where it would be possible to modify responses to experiment with different signature results.

Modern CIG's use state-of-the-art digital hardware. Since digital hardware is being constantly upgraded and new capabilities

are being added, it can be assumed that future CIG equipment will have more capabilities (texture, curved surfaces, etc.) and be simpler at the same time.

The most difficult problem in the CIG is the generation of the data base. If each edge had to be hand-generated, it would be very difficult and very costly to design new data bases. However, new techniques are constantly being developed to generate data bases using automatic techniques that will greatly reduce costs. DMAAC data is being used, but extensive rework of the data is necessary to provide adequate visual correlation and smoothness.

Data base generation will continue to be the most difficult area in which to ease costs. It is important for FDL's cost-effective use that the existing inventory of data bases be maximized if a CIG is purchased. Existing data bases can be upgraded as needed. It would also be worth the extra cost to purchase some of the new programs capable of real time feature growth, as described in Section 5.1.4.

6.3.4 EW Systems

In order to define the simulation requirements for EW systems a number of variables have to be defined. First, the type of system to be simulated should be defined. The sensor characteristics, Section 3.2.1.6, the sensor study SOW, and the 5-Year Plan provide sufficient information to do so.

The following is a basic description of the generic airborne EW sensor system to be simulated. This system includes:

1) Multi-antenna/receiver (wide band rather than narrow/swept receiver)

2) Central processing unit for:

Threat identification
Threat prioritization
Threat location
Field programmable threat tables

3) On-board computer interface for:

Threat dependent ECM interface	mission/aircraft
Weapon dependent armament interface	dependent

o Warning displays

Visual: on shared multifunction display
Aural: threat pulse trains and special warning tone(s)

This system, due to its processing capability, will have the output visual display function separated from the rest of the system. This means that only processed information will be displayed in form of x, y located (relative to aircraft heading) symbols. In addition, the aural warning system will consist of both threat pulse trains and special warning tones.

Historically, a number of approaches have been used to solve this simulation problem. They are listed below with their advantages and disadvantages:

1) Fly aircraft against real world or simulated threats.

ADVANTAGES	DISADVANTAGES
a) Realistic	a) Very expensive
	b) Difficulty in providing dense threat environment
	c) Training security
	d) EW system dependent.

2) Entire aircraft hardware system receiving RF level injected threat signals.

ADVANTAGES	DISADVANTAGES
a) Simulation yields realism - System responds as in real world (if threat signals are realistic)	a) Expensive and cumbersome especially for dense threat environments.
b) Audio display for free	b) Changes difficult since mostly a hardware system.
	c) EW system dependent.

3) EW system processor stimulated by video level pulse trains, processor driving the display.

ADVANTAGES	DISADVANTAGES
a) Simulation realism good.	a) Pulse train generation hardware must be flexible enough to allow for changing threat environment (preferably via software).
b) Audio for free.	b) EW system dependent.
c) Display driven by processor.	

4) Functionally simulated processor with special hardware driving actual or simulated display.

ADVANTAGES	DISADVANTAGES
a) Least hardware, most flexibility can be system independent.	a) Audio must be generated separately.
	b) Can be difficult simulation task if a particular processor is to be simulated, since data on processor quirks is rarely available.

Prior to selecting an approach, the following FDL requirements should be taken into consideration.

1) Only one system is to be built, so non-recurring expenditures should be minimized.

2) The simulated system should be generic; independent of current or possible future EW systems or easily modifiable to represent future systems.

3) Due to (2) above, system does not necessarily require super hi-fidelity simulation; simulated system will be used in evaluating things other than EW correctness.

4) System should be modular and flexible in order to meet FDL and computational resources.

Approaches 1-3 above are all system dependent, i.e., they use part of a real-world system. Approach 4 can be made system independent if certain assumptions concerning the processor are made. Approach 4 also has enough flexibility to allow the simulation of the system to be implemented in stages. This implementation can encompass anything from a simple warn system to a dense emitter environment system. In addition since the visual display contains only processed data, the display can be a simple low data content

type. Thus, Approach 4 is the recommended approach for a generic type EW system simulation.

A block diagram of a basic generic EW system simulation derived above is shown in Figure 6.3.4-1. The system consists of a software-driven audio and visual display.

The software section consists of generation of a threat environment, threat detection/identification, and a display driver.

The threat environment is simply a set of target kinematics equations. They determine, in body frame, the relative azimuth, elevation, and range from the aircraft to the target. This subsystem may be a simple system controlled by an instructor, or a complex mission environment stored on disk. The main calculations may be performed at 5 per sec, with the outputs extrapolated to the display driver output rate (perhaps 15-20 Hz).

The threat detection equations combine two major real-world blocks. Here, the SNR characteristics of threat signal propagation and the EW system receiver/processor are taken into account. Here again, considerable flexibility is allowed by the chosen approach. The system can be a simple threat versus display cross reference or a system that actually calculates real-world SNR ratios and includes particular processor properties. In the simple system, the processor can be assumed to be 100% correct in its decoding process. Detection may be based merely on threat range. Thus, it can be seen that in this type of generic system simulation, the simulated system can be made entirely independent of the processor. This allows for a relatively simple system simulation requiring small computational resources, yet it does not deprive the cockpit of realistic visual and audio display.

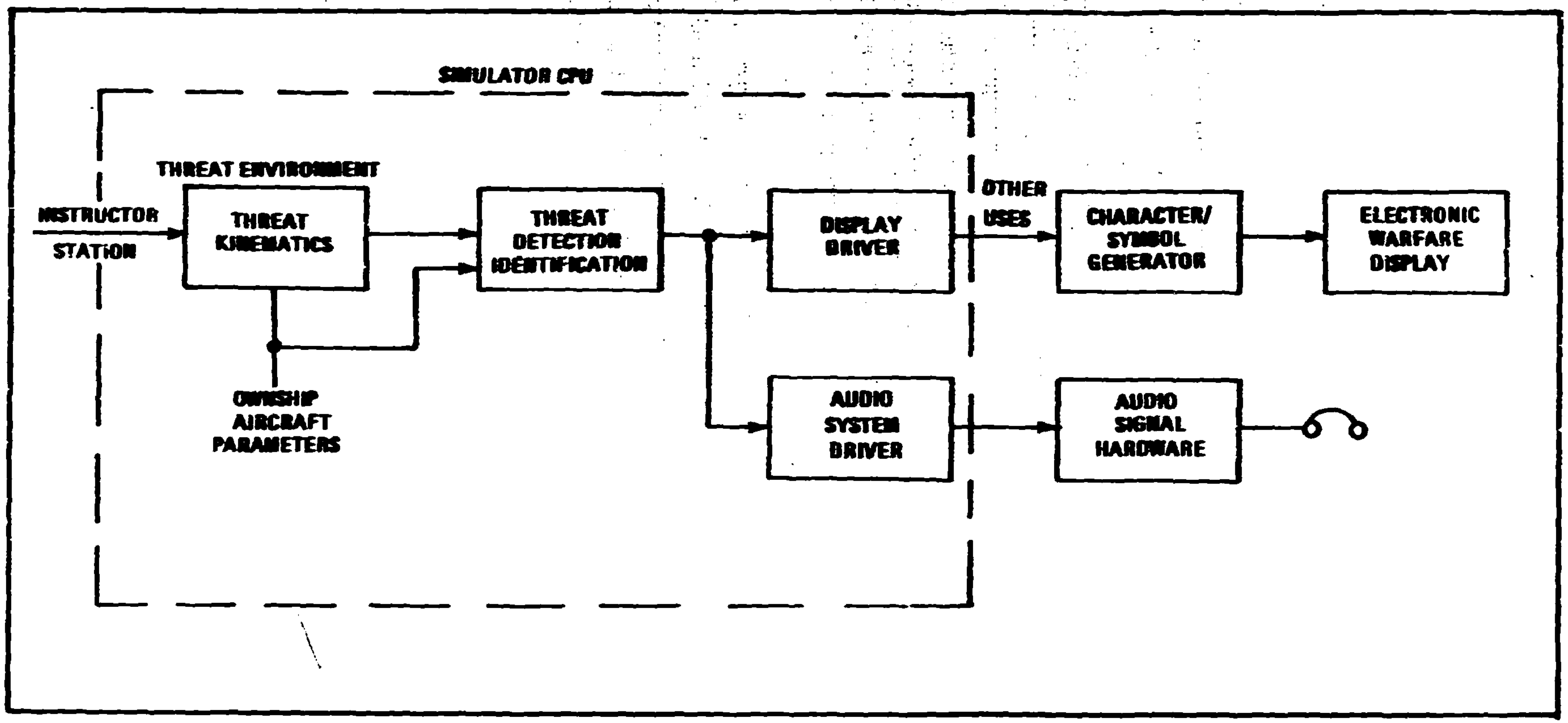

Figure 6.3.4-1 BASIC EW SYSTEM SIMULATION

The audio display can consist of a number of identical audio circuits whose outputs are summed together for the aircraft interphone system. The ear is not as critical as an EW system processor and many corners can be cut in generating realistic audio. Previous simulation experience shows that when this type of audio system sums approximately 10 threat signals together, it is difficult for the user to tell them apart. This leads to a design where there are a limited number of audio channels, the only provision being that when the channel limitation is reached, the first signal (the one that has been on the longest) is replaced by the newest. This always alerts the user to the fact that something new was added as a threat first appears; however, with many threats audios present it is impossible to tell if anything is incorrect.

This allows for the basic audio generating system to be simple as long as a sufficiently broad range of pulse trains can be generated. The pulse trains do not have to be as accurate as would be required for EW processor inputs, due to the fact that one cannot hear the difference. In addition, many processors stretch the pulse trains for the audio output. Thus, the audio system can consist of a set of identical audio generators that are all summed for the final audio output.

The previously described simple system can be modified (expanded) if a more complex EW system is desired.

This modification can be performed in steps, again allowing for flexibility.

1) For one, the threat environment can be enlarged just by supplying more computer resources, but using existing equations.

2) As mentioned before, the detection and processor criteria can be made more stringent.

3) The threat environment can also be interfaced to a device to provide threat terrain occulting. Again, flexibility is allowed. An algorithm with a random number generator and local terrain roughness indication may be sufficient if only an ARLMS is available. It may be possible to perform an actual occulting check in this type of system depending on the capabilities of the ARLMS flying spot scanner. If a DRLMS exists, the systems can be interfaced to provide actual occulting calculations.

4) A more complex EW simulation may also benefit from an interface with an on-board computer for armament selection and release on suppression aircraft; or an interface to existing on-board jammers providing a simulation of a power management system.

5) In addition, algorithms can be developed that make the simulated aircraft interactive with the threat environment. This can be carried to the point where threat weapons may affect the operation of the simulated aircraft.

A block diagram of such an expanded generic EW system simulation can be seen in Figure 6.3.4-2. It is the basic system of Figure 6.3.4-1 with a number of independent building blocks added to provide the desired system.

The entire system can be designed to offer a large amount of flexibility that is only limited by people or computer resources.

<u>EW DISPLAY SYSTEM</u> - Compared to a visual system, an EW system display is a low data content display. The display is symbols or characters of processed data rather than live video data (high-data content). In addition, since the decision making is done by

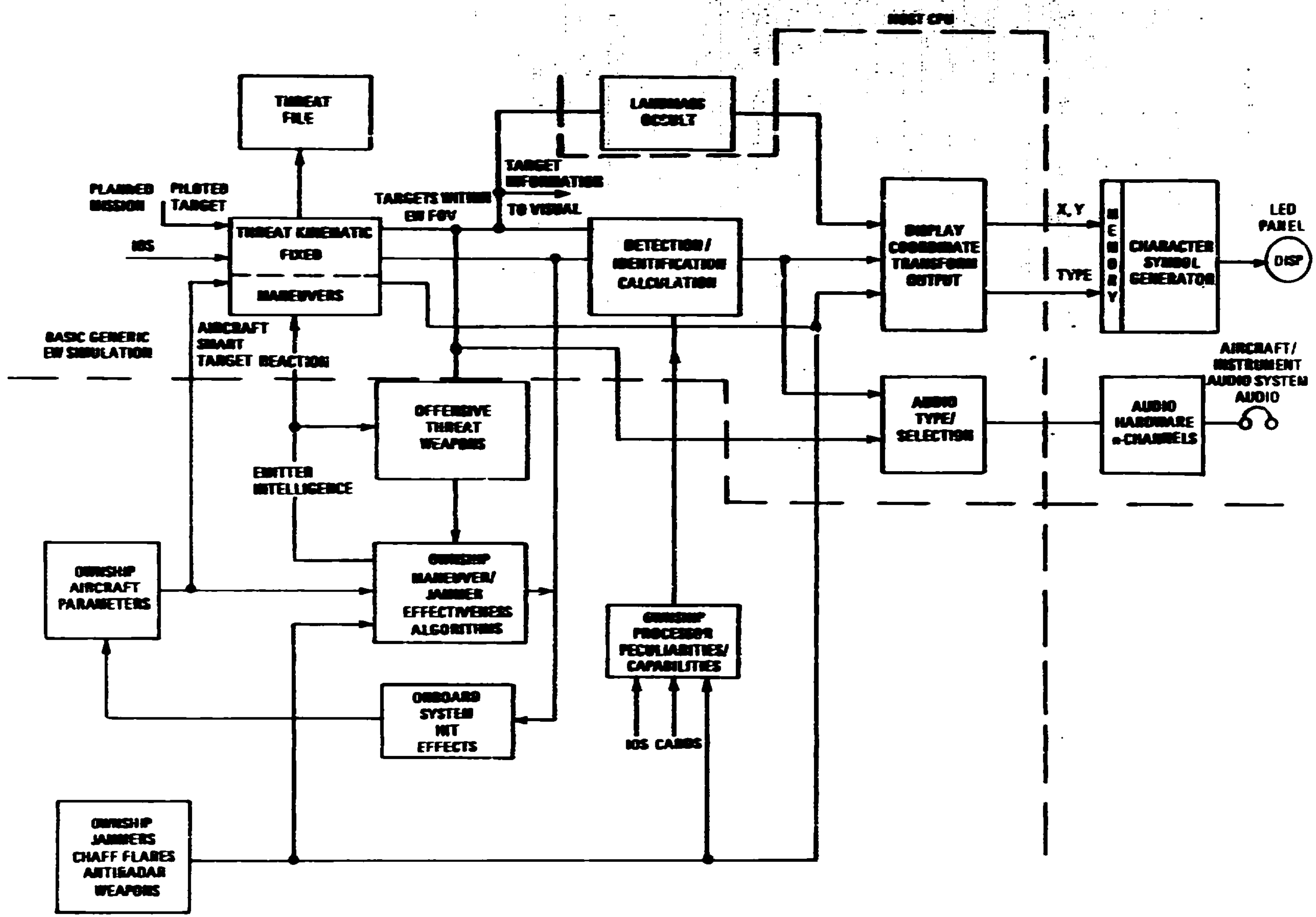

Figure 6.3.4-2 EXPANDED EW SYSTEM SIMULATION

the processor and not by the air crew, the display is usually entirely (time and data) separated from the processor. This fact, and the desire for a generic simulation, allow considerable selection flexibility for the EW visual display. (The audio display system has been described previously). The display is a mere X-Y position display of processed threats and/or means for an automatic system to display to the crew certain decisions it has commanded. The display is not used by the crew to analyze video data.

These facts allow a display system to be selected with the following general specifications:

1) Compact size (approximately 4 in. by 4 in.)
2) Alphanumerics
3) Special symbols
4) Black and white (color not necessary)
5) 1 to 20 Hz update rate (refresh rate of display is a separate matter)

These specifications are similar to many other cockpit system display requirements. This makes it an ideal candidate for a general type of display that can be shared for a number of simulation requirements. The sharing may be mission-segment oriented (EW during one part of mission, NAV indicator during another part of the mission) or the display may be used for different purposes depending on the simulation requirements.

The outputs of an EW processing system can be displayed in a number of ways. Some of these are:

1)	Warning lights	A simple warn light versus reception quadrant indication.

2)	Stroke writing of symbols	Since a unique set of EW identification symbols could probably be used, this makes the display system unique.
3)	Raster TV display	A number of standard raster scan systems can be chosen. Selection would depend on other systems with which this display would be shared. Sharing examples include EO on-board sensor, weapon display, or any aircraft system that matches selected raster. Aside from the raster limitation this system is fairly versatile. Other raster systems could be scan converted for display. Characters can be via five by seven dot matrix generators. This is an overkill for the EW display, but would provide versatility for sharing with many other high-data content system displays.
4)	LED dot matrix	This would be a low-data content display since resolution is 64 lines per in. This is sufficient for an EW or NAV display and provides for future versatility.
5)	Digital Raster Graphics (DRG)	System would allow 1024 by 1024 pixels which is more than sufficient for many displays. System would only give two levels of intensity (on or off) which is sufficient for

low-data content displays. However, CRT and deflection would be sufficient to display high-data content when image generator is available.

It would appear that a combination of 4) and 5) above would be the most versatile type of display. This system would be a DRG which can drive a 1024 by 1024 display (if available) or, on a 4:1 address compression (drop 2 LSB of X-Y), it can be used to drive a LED dot matrix type of display. This combination is also chosen since the building of a drive for an LED matrix would essentially be similar to the DRG but would offer more future versatility.

6.3.5 Radar Simulation

FDL has a model T-10 ARLMS. The simulator was built in the late 1960's or early 1970's. These systems are film plate limited at 250 ft resolution and improvements are difficult and expensive. Modern DRLMS's provide a significant increase in performance and flexibility. A variety of options are available in the modern units which increase the versatility of the units to allow them to simulate many different types of radars.

6.3.5.1 Analog Radar Simulation

The ARLMS system now installed at FDL is inherently limited by the film plates. The FSS has sufficient resolution so that it is not a limiting factor is the system resolution. Any modifications or improvements to the T-10 type landmass system will be very expensive and time-consuming due to problems associated with changes to the landmass film plates (see section 5.1.5.5). In any event, even if this cost burden is accepted, the performance of this system will remain marginal due to the inherent limitations of the analog design. Some additional gains could be made through modifications of the FSS deflection system. However, since the

system is limited by the resolution of the film plates, only minor gains can be expected.

If major improvements in performance are required the acquisition of a digital system is recommended.

6.3.5.2 Digital Radar Simulation

Section 5.1.5.4 discusses the DRLMS approach. Table 5.1.5.4.6-2 shows the major advantages of the DRLMS. The digital approach to radar simulation, like the digital approach to visual scenes, provides great versatility in providing varied formats and sensor characteristics. The performance of modern digital systems meets most of the criteria of advanced radar systems like that of the C-130 and B-52, and the F-16 systems will be operational within the next few years. Like CIG systems, no startling performance advances can be expected over the next five years, but improvement can be expected in system simplification and a continued effort to update performance.

While DRLM's have many limitations in their presentation as does the CIG, the approach is still a vast improvement with continual radar advances. With the trend toward abstract symbology being used to identify potential targets, the digital simulation approach can be modified to adapt to new codes and presentation with greater ease than an analog system. Growth will include new approaches such as "look down" and "shoot down" weaponry that will cause extensive changes in radar presentation, impacting radar simulation, especially as applied by FDL. These changes can more easily be absorbed by a digital approach than by analog.

6.4 RECOMMENDATIONS

The primary factors to be considered in establishing FDL's sensor simulation capability are funding, the state of the art in

both sensor and simulation technology, and facility schedules and plans as outlined in the 5-Year Plan. These factors are obviously interrelated but the funding profiles available to FDL are of prime importance. The available funds will significantly influence the approach to and the sequence of facility modernizations. Obviously, a major and abrupt switch to digital hardware such as CIG and DRLMS will require large initial expenditures and cause lengthy interruptions to facility operations. An alternate approach would be to use existing equipment to its best advantage through a modification program and simultaneously begin the long-term acquisition of more sophisticated hardware.

In recognition of these cost and schedule factors it is recommended that a multi-step approach to upgrading the sensor simulation capability at FDL be adopted. A carefully planned approach will provide useful simulation capabilities over the interim period required to fund and acquire the ultimately desired facilities.

The first approach (i.e., completely modernizing the facility and procuring new equipment) should be considered as the long-term goal. The conclusion reached during the study is that new sensors are emerging which provide a much higher capacity for information than present systems. These new sensors will demand new approaches to their simulation and reach beyond the practical and theoretical limits of present or upgraded FDL equipment. The new approaches will include an all-digital approach to sensor simulation. New CIG equipment and DRLMS's will be needed to meet the goals of the upcoming years. Although this represents the most complete and technically sound approach, the acquisition costs are high and the facility would not be responsive to immediate simulation needs, as procurement would probably take as long as 2 to 3 years.

The sequential approach recommended to avoid these problems is as follows:

1) Modify the existing CMS to gain IR and TV capability by incorporating different paints of varying reflectivity on the modelboard and different enhancement levels of video.

2) Augment the existing T-10 ARLMS as suggested in 5.1.5.5 and experiment with different combinations of varying levels of signals from the FSS scanning radar reflectivity transparency and radar terrain elevation transparency.

3) Start acquisition procedures for a CIG and a DRLMS.

Items 1) and 2) are short-range goals which can be accomplished at reasonable cost. A number of modification programs could be considered for the CMS. The following recommendations are made to upgrade the current FDL CMS's:

1) Optical redesign - Using Figure 6.3.1-1, and a knowledge of the mission requirement a tradeoff must be made to arrive at a desired optical design. An optical system could be configured with an iris to allow various apertures to be used, or for economy purposes, the lens could be scaled for a particular FOV and system resolution.

2) Optical probe servo upgrade - Useful image correlations can be obtained betwsen instrument and visual presentation by redesigning the servo drive package. The primary effort would involve adding position sensing devices to each of the servo drive systems. This effort will likely lead to adding more slip rings, moving of mechanical arms to provide clearance for position sensors of adequate resolution, and integrating closed loop feedback techniques either through the computer or through external electronic designs.

3) Probe protection - Low-level flight over general terrain boards is very difficult with standard probe protection networks. Improvements have been made over the years in implementation of probe protection schemes that account for any cause of model or probe error in position. Much effort has been spent at FDL developing software protection techniques, but this needs to be supplemented by newer hardware protection techniques developed for modern camera model systems.

Figure 6.4-1 shows the physical packaging of the Probe Height Sensor (PHS) and how it is mounted on the probe. The light is emitted by the laser, focused by the microscope objective, and folded close to the probe "snout" by the fold prism. After it strikes the modelboard it is gathered by the pick-up mirror, which folds the light through the bandpass filter into the lens, which images it to the linear array on the circuit board by way of a fold mirror. The mirrors are used to keep the packaging close to the axis of the probe to reduce inertia and avoid compromising the performance of the probe heading servo. Slip rings carry power into and signals out of the PHS since the whole device is carried with the probe heading assembly.

4) Increased pitch mechanism - Since many of the newer sensors have large pitch control, it is vital to increase the now limited pitch range by modifying the mechanisms. Since most techniques to increase the pitch control include adding a prism to replace the mirror, the impact of the prism should be studied. Prisms usually are bulkier than mirrors, so servo control and board clearance are affected. It would be appropriate to design a replaceable pitch mechanism to allow either a mirror or prism, depending on the mission involved. A further step would

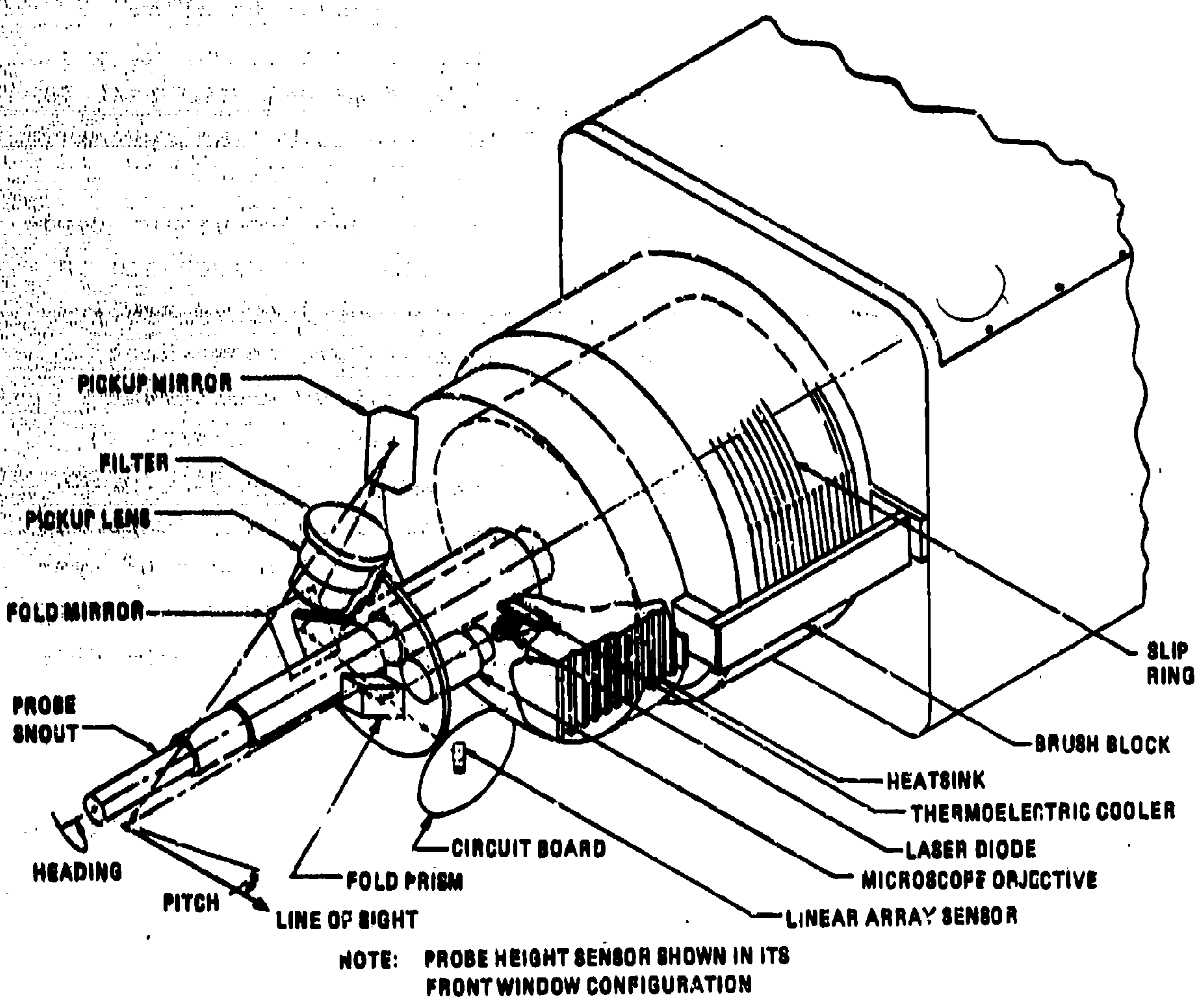

Figure 6.4-1 PHYSICAL PACKAGING OF PROBE HEIGHT SENSOR

be to have a series of mirrors to match the aperture used in the system, since the smaller the mirror (and the smaller the aperture) the closer the probe can get to the board.

5) Increased system resolution - Many of the modern revisions are designed around 875-line standard. The camera and probe system should be upgraded to allow performance at the 875-line standard, using some of the newer camera model techniques developed over the past 10 years. The latest visual systems are 1023-line systems.

In addition it is recommended that video processing capability be added for sensor simulation. As discussed in earlier sections, this processing capability is available off the shelf and although there are some short comings, it does provide a cost-effective short-term simulation capability for most sensors, especially in the IR and E-O category. A more ambitious modification would be to acquire a new probe with more pitch capability and to change the system to color. A number of systems of this type have been built and are in government inventory. The possibility exists that some equipment might be available for these modifications on a surplus basis.

This study has examined the details and limitations of CMS's in great detail. It should be noted that these modifications do not solve the major problems of narrow FOV closeness of approach, and correlation to out-the-window scenes and weapons.

This study has also examined the details and latent capabilities of the T-10 ARLMS. Since this system is primarily film-limited and since modifications to the tri-color plates are rather expensive, any one-time modifications to this system which would

generate significant performance gains are not considered to be economically feasible. However, it is known that the U.S. Air Force has embarked on a similar improvement program and it is highly recommended that FDL work with the appropriate U.S. Air Force program office to reduce or circumvent development costs. With the modifications proposed for the U.S. Air Force the T-10 would become a useful interim tool for radar simulation at FDL.

Finally, the long-range plan must be to acquire digital technology through a series of major acquisitions. The CIG should be procured first to provide a replacement for the CMS and eventually a DRLMS should be acquired to replace the T-10.

This systematic approach will provide immediate capability through the use of existing equipment, will allow acquisition costs to be distributed over longer time periods, and will allow as much time as possible for advancements in simulation technology before funds are committed.

6.5 COST ESTIMATES

Table 6.5-1 gives some relative cost estimates for existing hardware. These figures are intended only as guidelines and should not be interpreted as price quotations or even price estimates for a specific product line.

Obviously, these costs will vary with options, modifications, maintenance, and inflation, and therefore should only be used for comparison of major system approaches.

[redacted]

Table 6.5-1 COST ESTIMATES (MILLIONS)

F-111 CIG*	2.0
B-52 CIG*	4.0
DRLMS	4.0
ARLMS (upgrade based on U.S. Air Force T-10 B-52D approach)	1.0
CMS upgrade	1.0
Surplus CMS Adaptation**	0.5

* Hardware only -- does not include new data base efforts.

** If an operational probe system is available.

The major components of the F-111 CIG are frame calculator, scanline computer, video generator, CPU with peripherals, and a data base.

The major components of the B-52 CIG are essentially the same as that of the F-111 CIG. The cost increase is due to improved scene quality with reduced scintillation and reduced aliasing. Section 5.6.2 describes the methodology of B-52 EVS simulation.

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APPENDIX A

TEXAS INSTRUMENTS INFRARED/ELECTRO-OPTICS PRESENTATION

THERMAL IMAGE PROCESSING OVERVIEW

STATUS

- IN TODAY'S SYSTEMS, MOST IMAGE ENHANCEMENT, INTERPRETATION, AND REACTION FUNCTIONS ARE PERFORMED BY AN OPERATOR

TRENDS

- AVAILABLE OPERATOR TIME IS DECREASING
- SENSOR INFORMATION CAPACITY IS INCREASING
- REQUIREMENT FOR IMAGE PROCESSING IS INCREASING

BARRIERS

- IMAGE UNDERSTANDING
- DEMONSTRATED ALGORITHMS
- COMPONENT TECHNOLOGY

TI THRUSTS

• DATA BASE • ALGORITHM DEVELOPMENT • SIMULATION CAPABILITY • DIGITAL SCAN CONVERTER	+	• ADVANCED SENSORS • ADVANCED COMPONENTS	=	• IMPROVED CURRENT GENERATION SYSTEMS • NEXT GENERATION SYSTEMS

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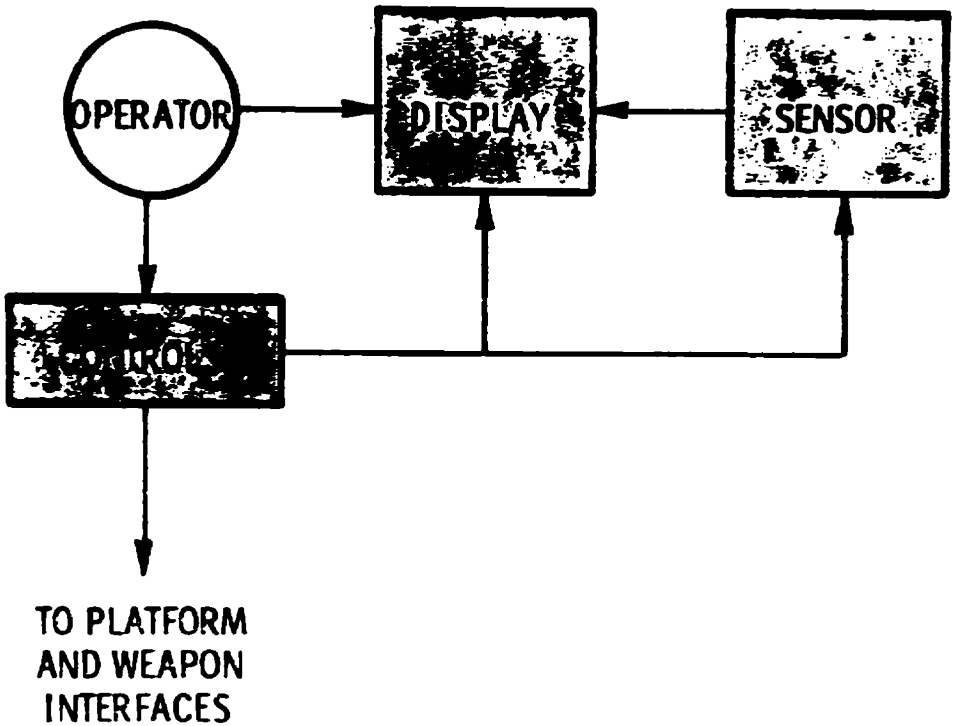
ELECTRO OPTICS SYSTEM EVOLUTION

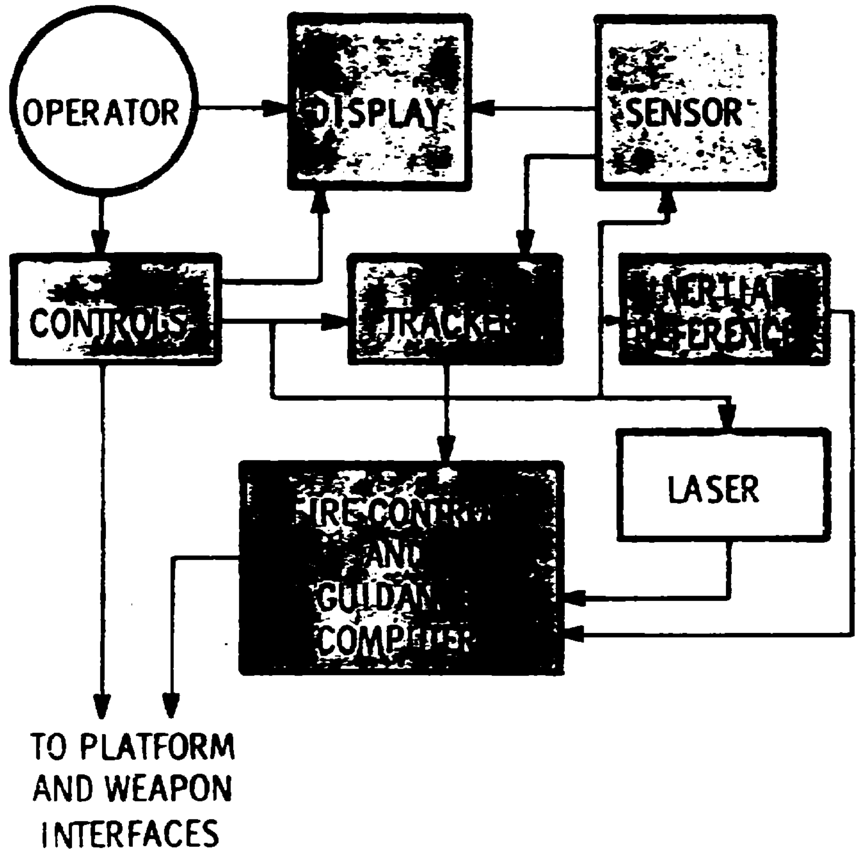


FUNCTIONS

SYSTEM	OPERATOR
IMAGE FORMATION	SENSOR CONTROL
	DISPLAY CONTROL
	DETECTION
	RECOGNITION
	MANUAL TRACK
	PLATFORM CONTROL
	FIRE CONTROL

05/04/79 DL 01-961

ELECTRO OPTICS SYSTEM EVOLUTION



FUNCTIONS

SYSTEM	OPERATOR
IMAGE FORMATION	SENSOR CONTROL
	DISPLAY CONTROL
	DETECTION
	RECOGNITION
AUTO TRACKING	~~MANUAL TRACK~~
	TRACK ACQUISITION
RANGING	LASER CONTROL
STABILIZATION	PLATFORM CONTROL
WEAPON POINTING	FIRE CONTROL

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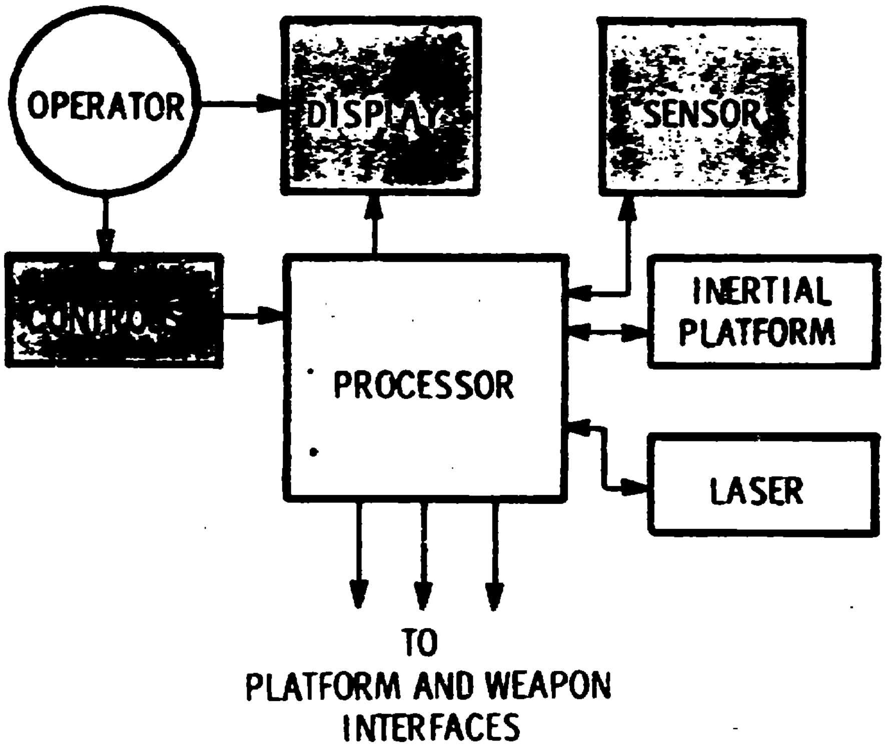
ELECTRO OPTICS SYSTEM EVOLUTION



FUNCTIONS

SYSTEM	OPERATOR
IMAGE FORMATION	
SENSOR CONTROL	~~SENSOR CONTROL~~
DISPLAY CONTROL	~~DISPLAY CONTROL~~
CUEING	DETECTION
TARGET CLASS.	RECOGNITION
AUTO TRACKING	~~MANUAL TRACKING~~ ~~TRACK ACQUISITION~~
AUTO RANGING	~~LASER CONTROL~~
PLATFORM CONT.	~~PLATFORM CONT.~~
FIRE CONTROL	~~FIRE CONTROL~~

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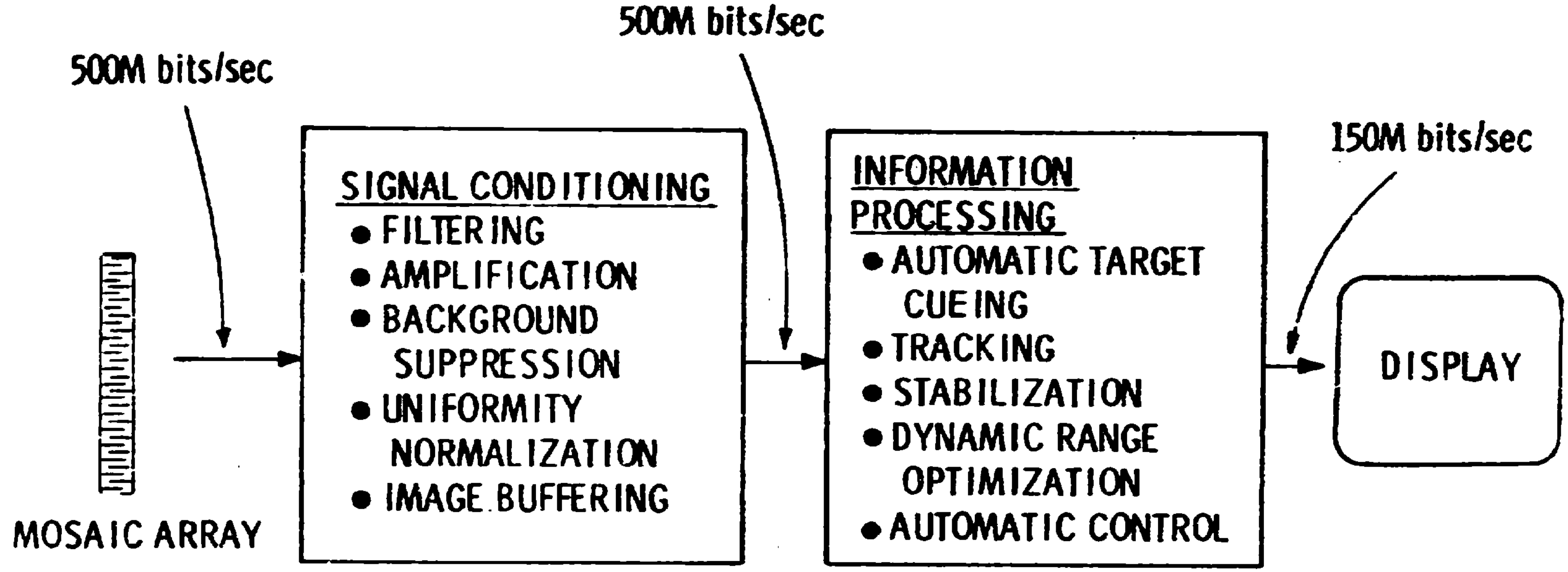
FLIR PROCESSING THRUSTS



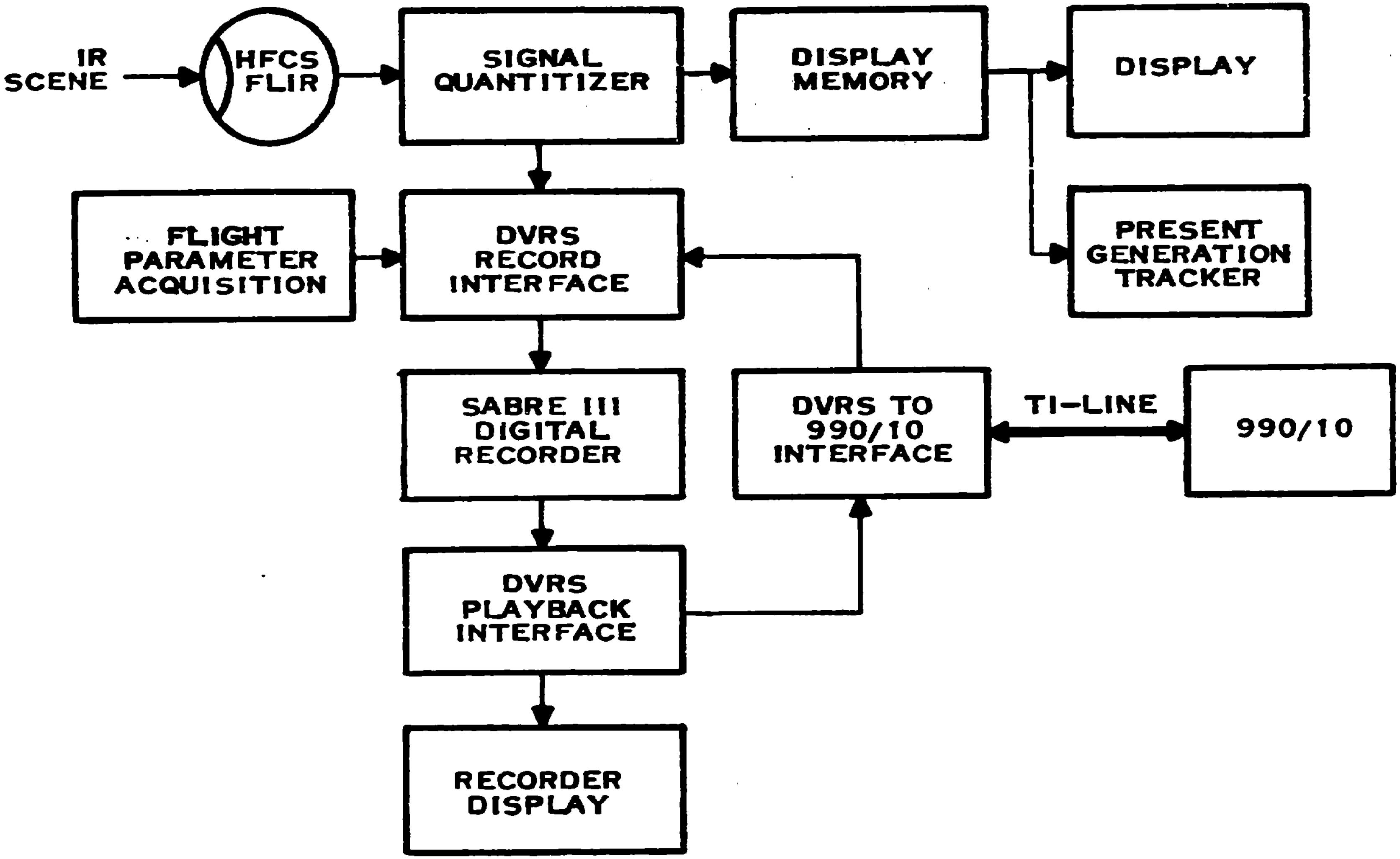
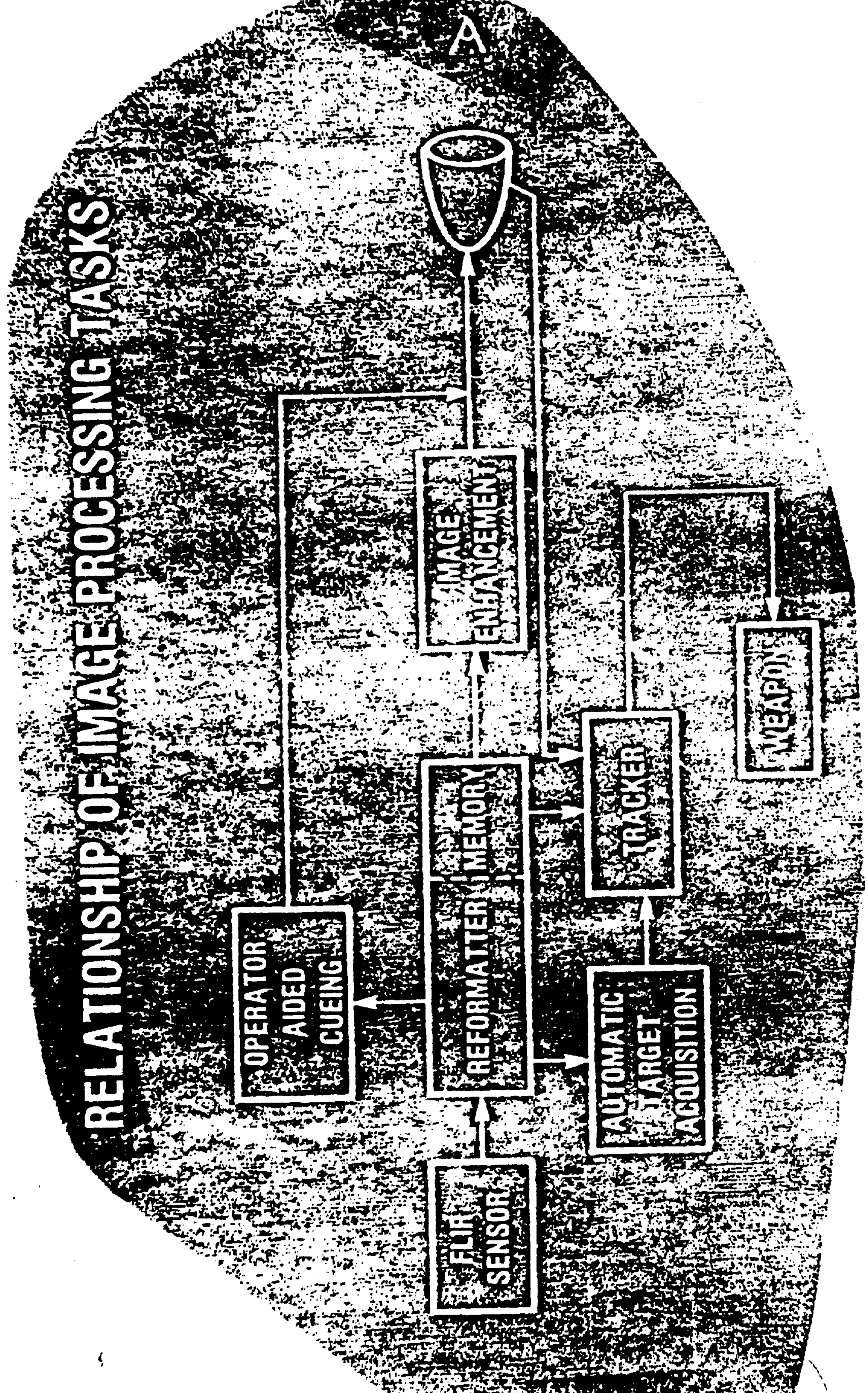


Figure 1. Data Acquisition System


RELATIONSHIP OF IMAGE PROCESSING TASKS
FLIR SENSOR
REFORMATTER MEMORY
OPERATOR AIDED CUEING
IMAGE ENHANCEMENT
AUTOMATIC TARGET ACQUISITION
TRACKER
WEAPON
A

IR IMAGE PROCESSING

AREAS OF INVESTIGATION

- IMAGE ENHANCEMENT - MOST EMPHASIS (DSC PROPOSAL AND SATIS EFFORT)
  - STREAK REDUCTION
  - AUTOMATIC GAIN CONTROL
  - DYNAMIC RANGE COMPRESSION
  - STABILIZATION
- AUTOMATIC TARGET ACQUISITION - INCREASING EMPHASIS
  - FULLY AUTOMATIC TARGET ACQUISITION - HIGH PERFORMANCE FLIR; LANTIRN, DARPA FIRE AND FORGET PROGRAM
  - FULLY AUTOMATIC TARGET ACQUISITION - LOW PERFORMANCE FLIR; LOAL FLIR ABOARD A MISSILE, E.G. IRGD
  - OPERATOR AIDED CUEING - AUTOMATICALLY DESIGNATE POTENTIAL TARGETS AND LET OPERATOR MAKE FINAL DECISION; RPV/CLGP; AAH/HELLFIRE

02-22-80, RLS, 0968

ALGORITHM DEVELOPMENT

- IMAGE ENHANCEMENT
- OPERATOR AIDED CUEING
- TRACKING

11-30-79, JBA, 0968

AUTOMATIC TARGET ACQUISITION

- SEARCH AND DETECTION - A CONTINUAL SCAN FOR POTENTIAL TARGETS. THIS MODE IS OPERATIONAL AT ALL TIMES.
- DISCRIMINATION AND PRIORITIZATION - POTENTIAL TARGETS DETECTED ARE SCREENED IN ORDER TO DISCRIMINATE BETWEEN REAL TARGETS AND NON TARGETS. FURTHER SCREENING ESTABLISHES PRIORITY FOR TARGET DESIGNATION.
- DESIGNATION AND ENGAGEMENT - THE HIGHEST PRIORITY TARGET IS AUTOMATICALLY SELECTED FOR TRACKING AND EITHER ENGAGED BY THE WEAPON SYSTEM OR OVERRIDDEN BY THE OPERATOR.

02-22-80, RLS, 0968

EVOLUTION AND SHIFT OF SENSOR FUNCTIONS

ACQUISITION	SEARCH DETECTION	SEARCH DETECTION DISCRIMINATION	SEARCH DETECTION DISCRIMINATION IDENTIFICATION	SEARCH DETECTION DISCRIMINATION IDENTIFICATION DAMAGE ASSESSMENT
ADVANCING INFORMATION PROCESSING EVOLUTION →				
THERMAL IMAGING SYSTEM	DISCRIMINATION IDENTIFICATION TRACKING DAMAGE ASSESSMENT	IDENTIFICATION TRACKING DAMAGE ASSESSMENT	TRACKING DAMAGE ASSESSMENT	TRACKING

02-22-80, RLS, 0968

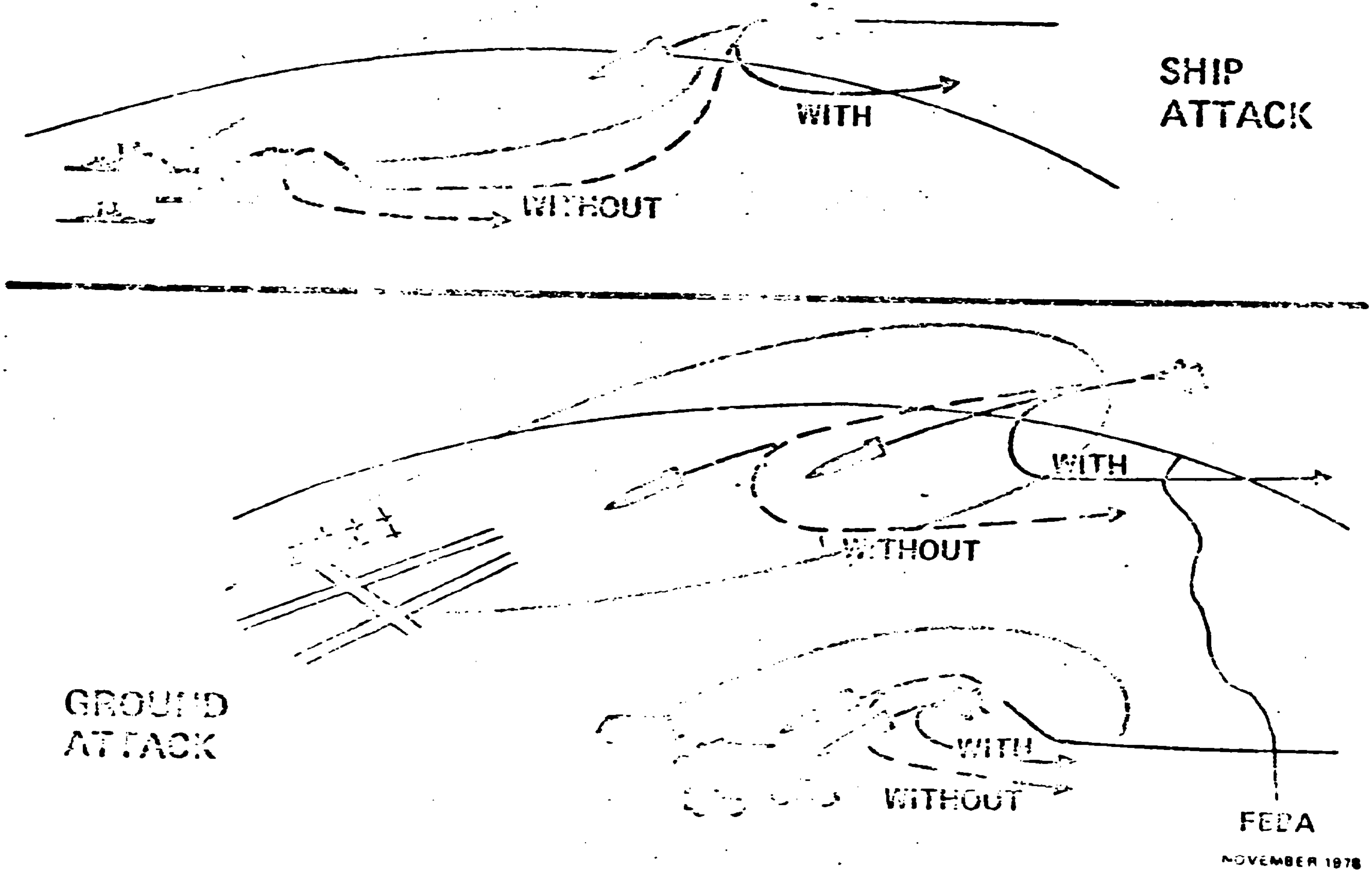
APPENDIX B

HUGHES AIRCRAFT PRESENTATION
ON
MULTI-SPECTRAL SENSOR CUING

MULTI-SPECTRAL TARGET CUEING (MYSTIC) FOR NAVY STRIKE WARFARE APPLICATIONS

- **WHAT:** THE IMPLEMENTATION OF MULTI-SENSOR, AUTONOMOUS TARGET ACQUISITION CAPABILITY IN ADVANCED ATTACK AIRCRAFT
- **WHY:** FOR EFFECTIVE STRIKE AND ACCEPTABLE SURVIVABILITY IN THE POST 1985 THREAT ENVIRONMENT
- **HOW:**
  - UPGRADED SENSORS
  - AUTOMATIC TARGET SCREENING/CLASSIFICATION
  - MULTI-SENSOR CORRELATION/CLASSIFICATION
  - PRECISION SENSOR ALIGNMENT AND TARGET HANDOFF

CANDIDATE PROFILES WITH AND WITHOUT ADVANCED INTEGRATED AVIONICS



THREAT-DERIVED OPERATIONAL NEEDS

SHIP ATTACK

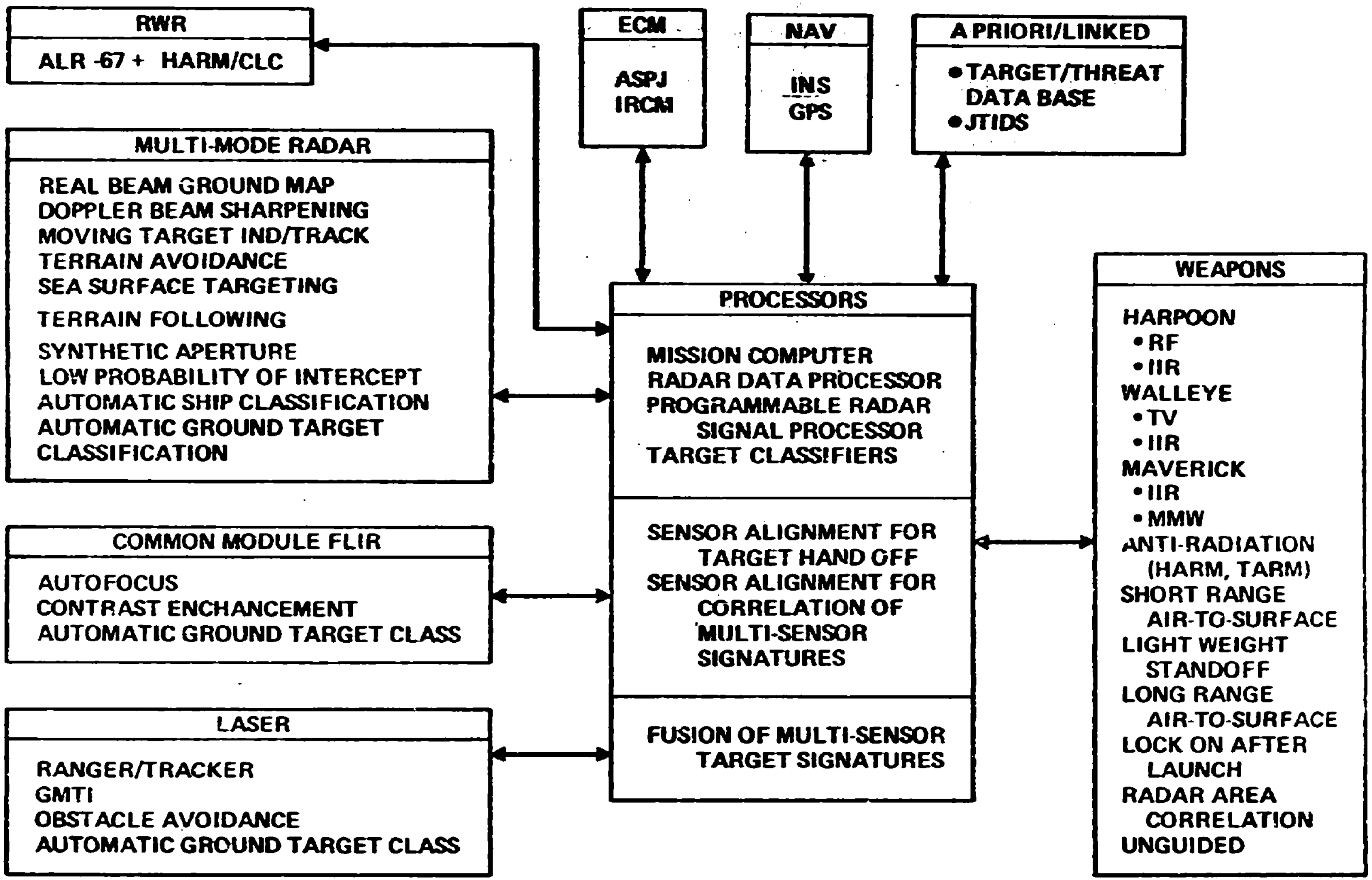
- STANDOFF IFFN
- STANDOFF WEAPON DELIVERY

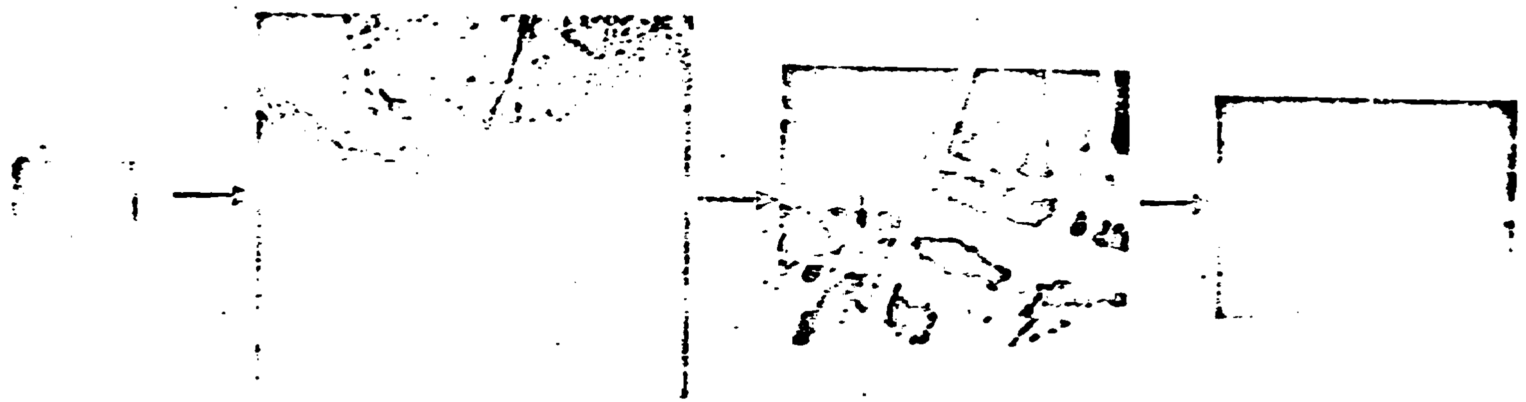
MOBILE GROUND TARGET ATTACK

- CLOSE AIR SUPPORT — DISCRIMINATE WARSAW PACT VERSUS NATO ARMORED VEHICLES
- INTERDICTION — DISCRIMINATE TANKS AND APCs VERSUS TRUCKS AND CIVILIAN VEHICLES
- DEFENSE SUPPRESSION — DISCRIMINATE MOBILE SAMs AND AAA FROM MOBILE ARMOR

CANDIDATE ADVANCED SYSTEM CONFIGURATION

HUGHES





LEVELS OF COMPLEXITY

1. MANUAL DESIGNATION VIA DISPLAY
2. AUTOMATIC HANDOFF VIA SIMPLE PROCESSING
3. AUTOMATIC TARGET RECOG/CLASS AND HANDOFF
   [RWR → RADAR ATS → FLIR ATS → WEAPON]
4. TARGET RECOG/CLASS VIA MULTI-SENSOR CORRELATION
   [RWR + RADAR ATS + FLIR ATS] → WEAPON

HUGHES

RESULT OF MULTI-SENSOR CONFIRMATION

- ENHANCED CONFIDENCE OF CORRECT TARGET ACQUISITION
- REDUCED FALSE ALARMS
- DISCRIMINATION OF REAL TARGETS FROM DECOYS
- REDUCED SUSCEPTIBILITY TO COUNTERMEASURES
- REDUCED TIMELINE

STUDY METHODOLOGY RESULTS IN CONCLUSIONS BASED ON EFFECTIVENESS AND COST COMPARISONS

- DEFINE TARGET AND THREAT MODELS
- DEFINE MISSION REQUIREMENTS
- TRANSLATE INTO SYSTEM, TECHNICAL REQUIREMENTS
- ASSESS SENSOR/PROCESSOR TECHNOLOGIES
- FORMULATE FIRE CONTROL SYSTEM CONCEPTS
- DETERMINE FIGURES OF EFFECTIVENESS (FOE)
  - BOMBS AND GUIDED WEAPONS
  - WITH AND WITHOUT DEFENSE SUPPRESSION
- RANK SYSTEMS
  - FOE
  - LOSSES
  - COST
  - TGT ACQ/ID
  - CM SUSCEPTIBILITY
  - EXPOSURE TIME
  - PILOT WORKLOAD
  - AIRCRAFT PERFORMANCE
- STRUCTURE SIMULATION AND DEVELOPMENT PROGRAM FOR PREFERRED CONCEPT

AUGUST 1979

RECOMMENDED MULTISENSOR COMBINATIONS

HUGHES

VG 5937

Mission Phase	Primary Sensor	Secondary Sensor/ Data	Supplementary Sensors/Data
Cruise/Navigation	Radar Imagery • RBGM • DBS • SAR	Cartography	Symbology • Beacon • Prebriefed CP's • Warning Receivers • Stored/Linked Threat Data
Preliminary Target Acquisition • Long Range	Radar Imagery • DBS • SAR	Stored Imagery of Target Area	Symbology • Stored/Linked Target Data • GMTI • Warning Receivers • Stored/Linked Threat Data
• Intermediate Range	Radar Imagery • DBS • SAR	FLIR • Hot Spots	Symbology • Feature Extraction/Pattern Recognition Devices • Laser Spot Tracker/Ranger • GMTI • Warning Receivers • Stored/Linked Target/ Threat Data
Target Acquisition at Pop-Up • Stand-off Range	FLIR Imagery	Radar • Glints	Symbology • Automatic Target Cuing Devices • Laser Spot Tracker/Designator/ Ranger • Warning Receivers • Stored/Linked Target/Threat Data • GMTI, GMTT
• Stand-off to Minimum Range	FLIR Imagery • Processed	TV Imagery • Processed	

SIMULTANEOUS SENSOR PROCESSING FUNCTIONAL BLOCK DIAGRAM

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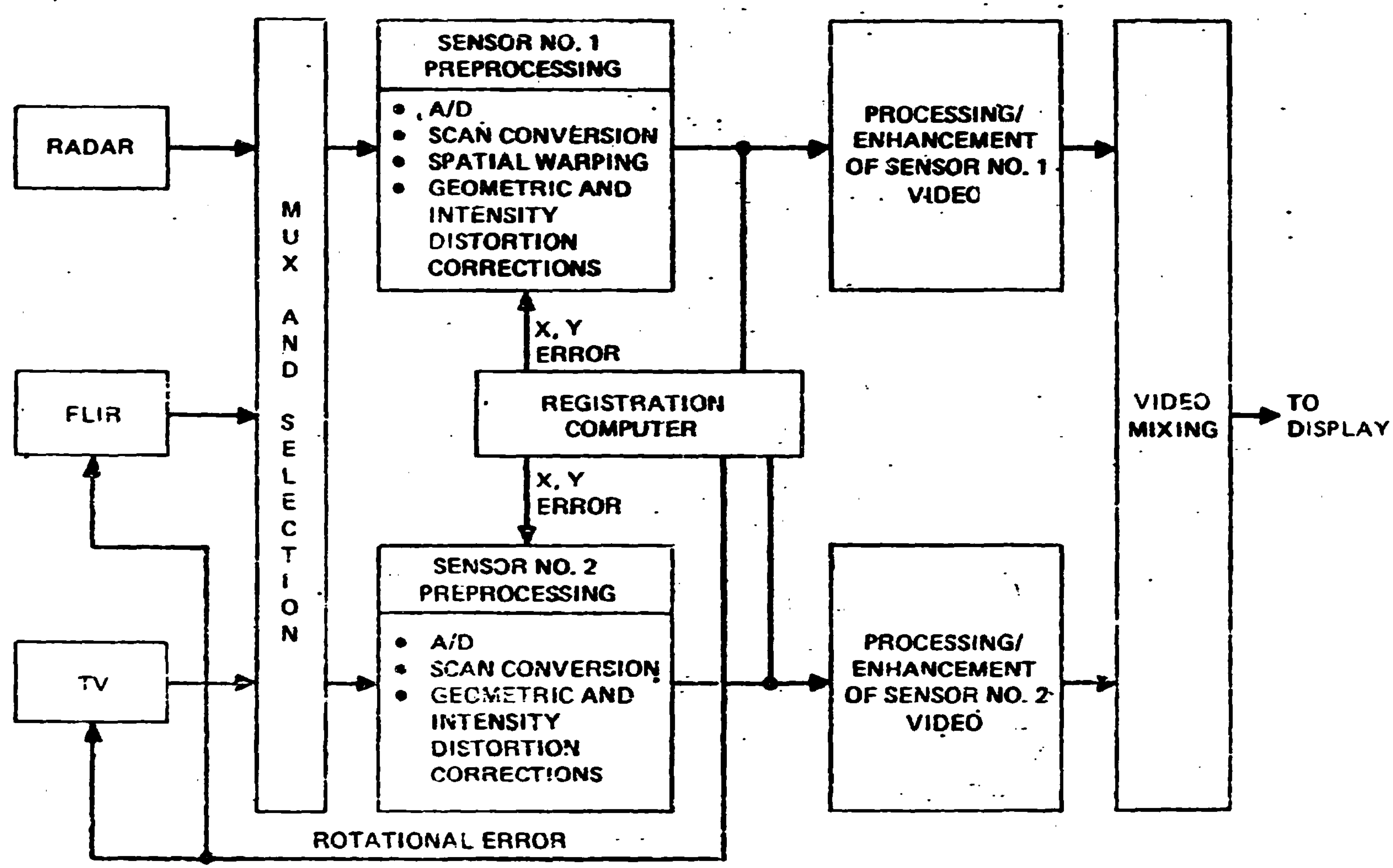
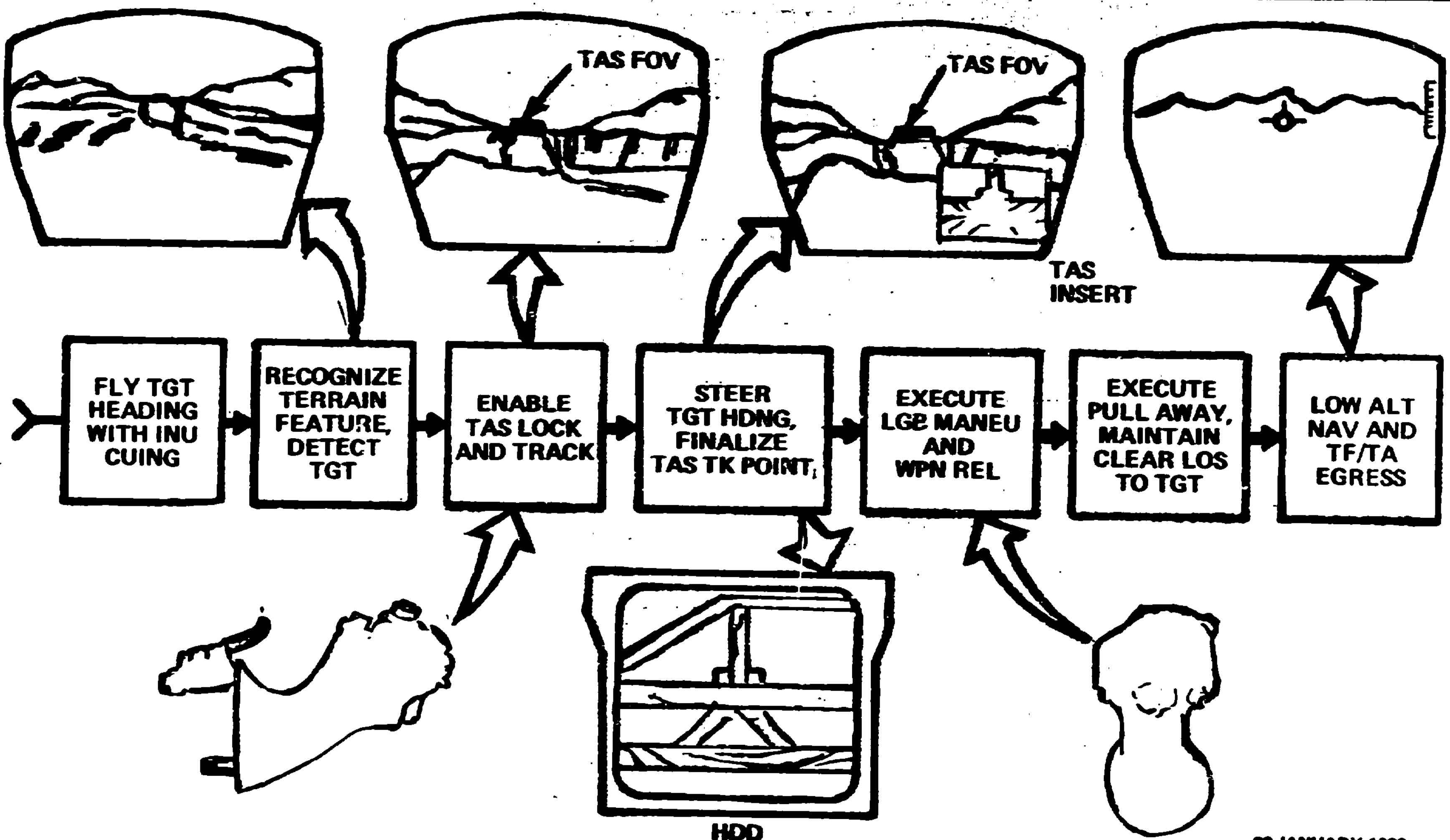


F-16 TYPICAL ENGAGEMENT SEQUENCE
AGM-65D ATTACK SEGMENT

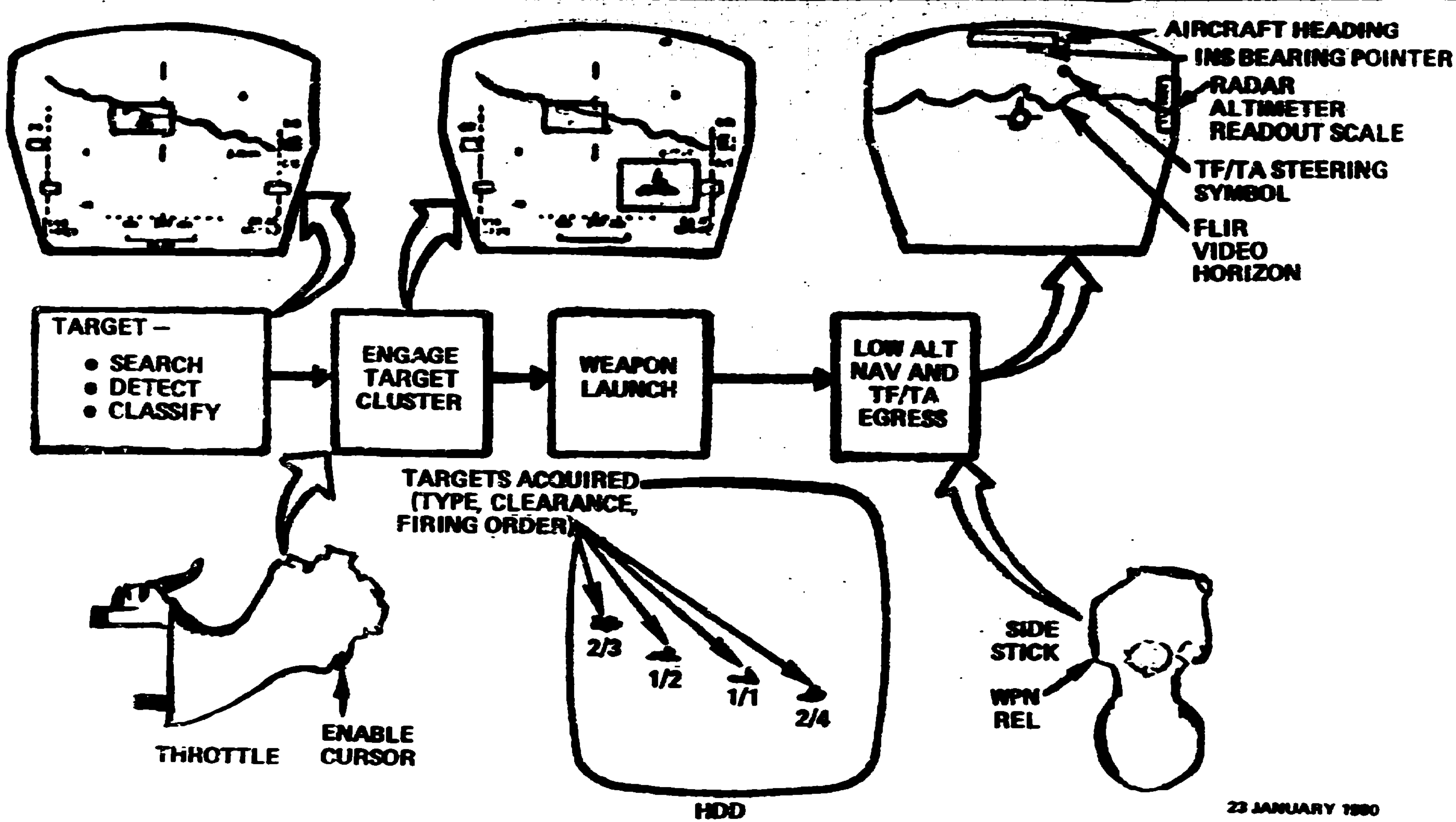
HUGHES



23 JANUARY 1980

F-16 TYPICAL ENGAGEMENT SEQUENCE
AGM-65D ATTACK SEGMENT

HUGHES



23 JANUARY 1980

EXTRACT FROM LANTIRN DRAFT RFP
1 OCTOBER 1979

- PROGRAM OBJECTIVES:

A. TECHNICAL DEMONSTRATION:

TWO CONTRACTS WILL BE AWARDED (COMPETITIVELY) FOR THE INITIAL RESEARCH AND DEVELOPMENT EFFORT (ITEMS 0001 AND 0002) WHICH CONSISTS OF EFFORT DIRECTED TOWARD DEMONSTRATING A FUNCTIONAL CAPABILITY TO PERFORM THE TARGET RECOGNITION FUNCTION. THE AIR FORCE CURRENTLY HAS A MAXIMUM TOTAL OF $15.8 MILLION BUDGETED FOR THE FUNCTIONAL DEMONSTRATION EFFORT.

B. FULL SCALE DEVELOPMENT:

APPROXIMATELY FOUR (4) MONTHS AFTER AWARD OF THE EFFORT IN PARAGRAPH 1 ABOVE, OPTION I, CONSISTING OF LINE ITEMS 0003 THROUGH 0015, WILL BE EXERCISED (WITH BOTH THE ABOVE CONTRACTORS) FOR THE REMAINDER OF THE RESEARCH AND DEVELOPMENT EFFORT. THE GOVERNMENT'S DESIRED APPROACH WOULD BE TO EXERCISE THIS OPTION I CONCURRENT WITH PARAGRAPH (A) ABOVE. HOWEVER, FUNDS PROBABLY WILL NOT BE AVAILABLE UNTIL APPROXIMATELY FOUR (4) MONTHS AFTER AWARD OF PARAGRAPH (A) ABOVE. A FIXED PRICE INCENTIVE FIRM (FPIF) TYPE CONTRACT IS CONTEMPLATED UTILIZING A CEILING OF 125% AND A 70/30 SHARE.

12/11/79,JKT,01-0959

LANTIRN POD REQUIREMENTS

1. OPERATE DAY AND NIGHT
2. BE SENSITIVE TO INFRARED ENERGY BETWEEN 8 AND 12 MICROMETERS.
3. PROVIDE WIDE FIELD OF VIEW NAVIGATION SENSOR IMAGERY AND NARROW FIELD OF VIEW TARGET ACQUISITION SENSOR IMAGERY
4. PROVIDE MANUAL/TERRAIN FOLLOWING CAPABILITY
5. PRESENT AUTOMATIC INFORMATION WHICH ELIMINATES PILOT WORKLOAD IN THE DETECTION, RECOGNITION, CLASSIFICATION AND DESIGNATION OF TACTICAL TARGETS AND WEAPON DELIVERY.
6. INTERFACE WITH THE F-16 AND A-10 AIRCRAFT
7. PROVIDE COMPOSITE VIDEO FOR HUD AND HDD
8. RECEIVE AND RESPOND TO PILOT CONTROLS
9. UTILIZE SELF-CONTAINED ENVIRONMENTAL CONTROL
10. PROVIDE FOR GROWTH OPTIONS:
    - INTERFACE FOR ADVANCED LASER GUIDED WEAPON
    - ADVANCED TARGET RECOGNIZE
    - TACTICAL CO_2 LASER

12/11/78,JKT,01-0959

MAJOR COMPONENTS

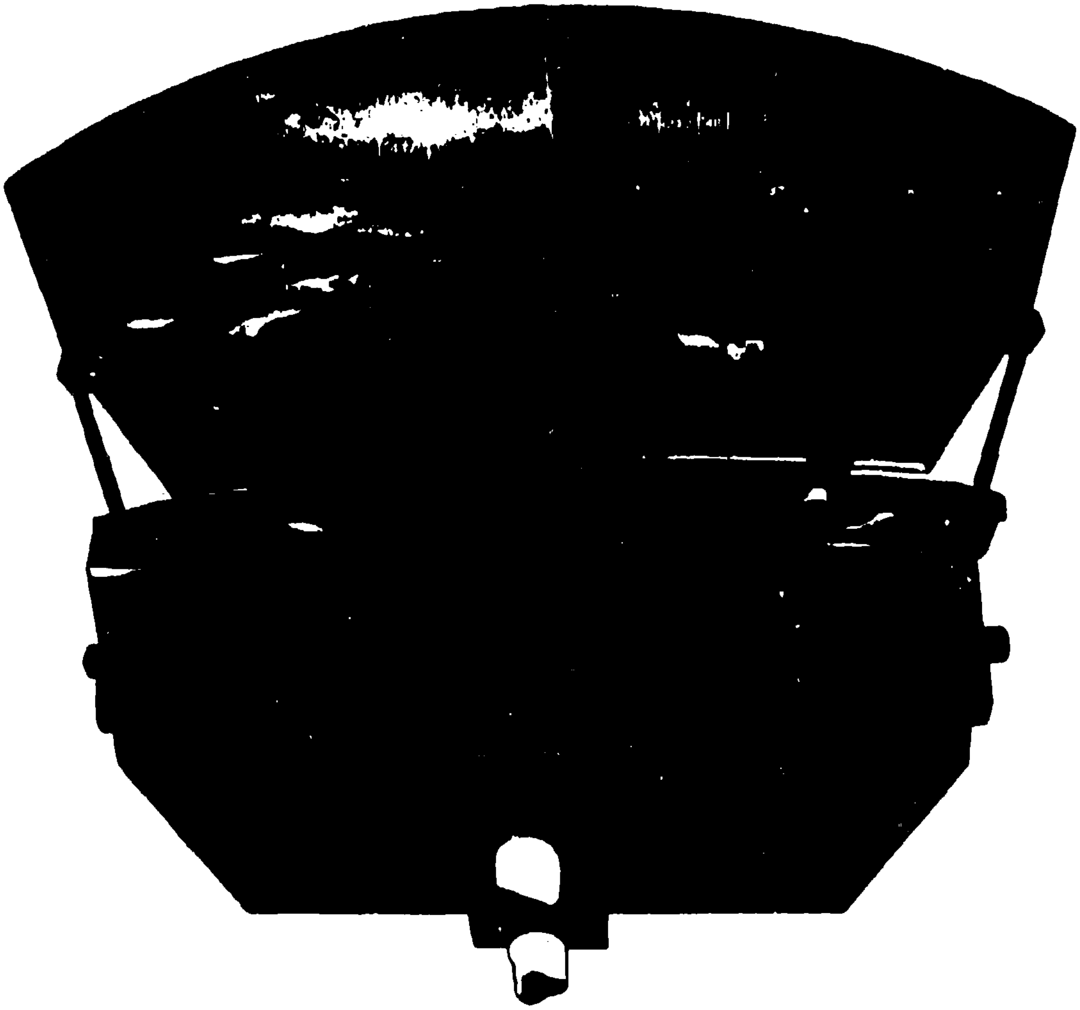
1. POD STRUCTURE
2. <u>FIXED IMAGING NAVIGATION SENSOR</u>
3. <u>MANUAL TERRAIN FOLLOWING SENSOR</u>
4. <u>TARGET ACQUISITION SENSOR</u>
5. YAG LASER DESIGNATOR/RANGER
6. ENVIRONMENTAL CONTROL
7. GIMBAL/STABILIZATION
8. CONTROLS AND DISPLAYS
9. BUILT-IN TEST
10. SUPPORT EQUIPMENT
11. <u>OPTICAL WINDOW ASSEMBLY</u>
12. <u>COMPUTER HARDWARE/SOFTWARE</u>

PROVISIONS FOR:

13. CO_2 MAPPING LASER
14. 3D TARGET RECOGNIZER

12/11/79,JKT,01-0959

Diffraction Optics widen, brighten view in new Hughes Head-Up Display



For Further Information Contact:

Advanced Program Development
Bldg R1/C331
Hughes Aircraft Company
P.O. Box 92426
Los Angeles, CA 90009
Telephone: (213) 648-0485

HUGHES

HUGHES AIRCRAFT COMPANY

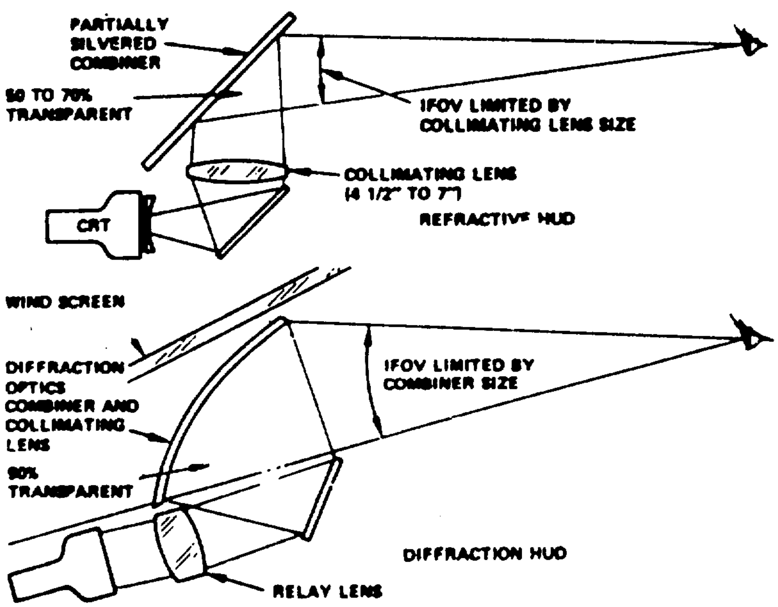
Development

The Air Material Department of the Swedish Defense Material Administration initiated the development of a diffraction optics HUD in 1975 with SRA Communication AB as the prime contractor and Hughes Aircraft Company as the subcontractor for the design and fabrication of the optical portions of the HUD. Through this cooperative effort the first flyable functional model of a diffraction optics HUD was produced in early 1977.

More than one hundred flights with the diffraction optics HUD installed in a Viggen test aircraft have been made, validating the basic design concept. The improvement in the combiner see-through, enlargement of the instantaneous field of view and increase in symbol brightness have been favorably accepted.

Concept

Hughes D HUD employs the unique concept of diffraction optics rather than the refractive optics used in previous head-up displays (HUD). Diffraction optics are true thin film lenses which are manufactured by holographic recording techniques. With this thin film lens technique, the collimating lens can be built into the combining glass instead of using a combiner which is a partially silvered mirror as is the case with previous HUDs. The diffraction optics combiner allows use of a single combiner for large fields of view. Spurious images and reflections are greatly reduced or eliminated as a result of this thin film lens and the single combiner.



The Diffraction Combiner/Collimater Provides a Larger Instantaneous Field of View.

Hughes D HUD with Combiners

Features

Large instantaneous fields of view (IFOV):

- ☐ The collimating lens is as large as the combining glass.
- ☐ Flight test D HUD IFOV is 20° vertical by 35° horizontal.
- ☐ Large, wide IFOV enhances capability to use FLIR/TV video on the HUD.

Brighter display:

- ☐ High efficiency with P-43 phosphor CRT is up to three times brighter than previous HUDs.
- ☐ Symbology is visible when flying into the sun.
- ☐ FLIR/TV video can be used over a wider range of ambient light conditions.

Improved "see-through" capability:

- ☐ Narrow spectral properties renders the lens practically transparent to the pilot's view.
- ☐ Air-to-Air/Air-to-Ground Visibility is improved.
- ☐ Flight safety is enhanced in low altitude-poor visibility conditions.

Reduced obscuration:

- ☐ No support frame is required, only minimum stabilizer struts.
- ☐ Targets and outside world are not obscured. No need to look "around" support frame.

Lower life cycle cost:

- ☐ The CRT/HVPS components have been the primary cause of system failures. Higher optical efficiency reduces the required stress level on the CRT and HVPS, resulting in improved reliability and reduced maintenance requirements.

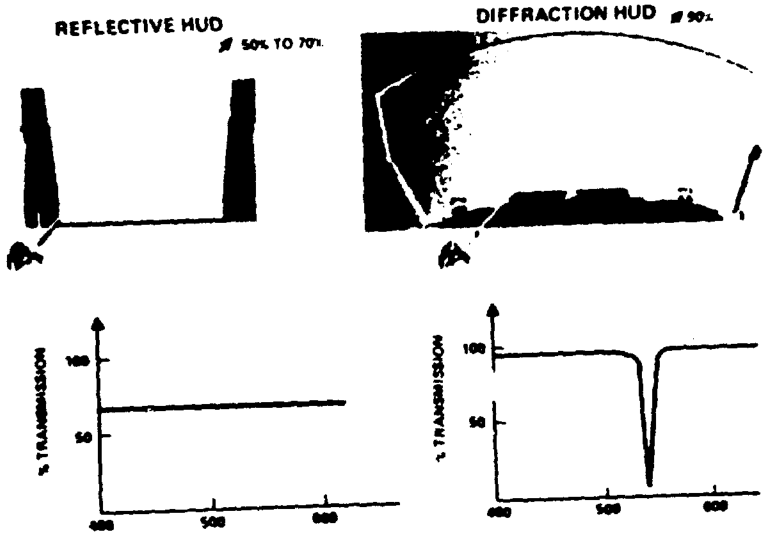
Operationally tested:

- ☐ Tested on "Viggen" fighter aircraft since 1977.
- ☐ Accuracy is validated.
- ☐ Environmental stability is proven.
- ☐ Sun Reflection is less than other HUDs.

Comparisons

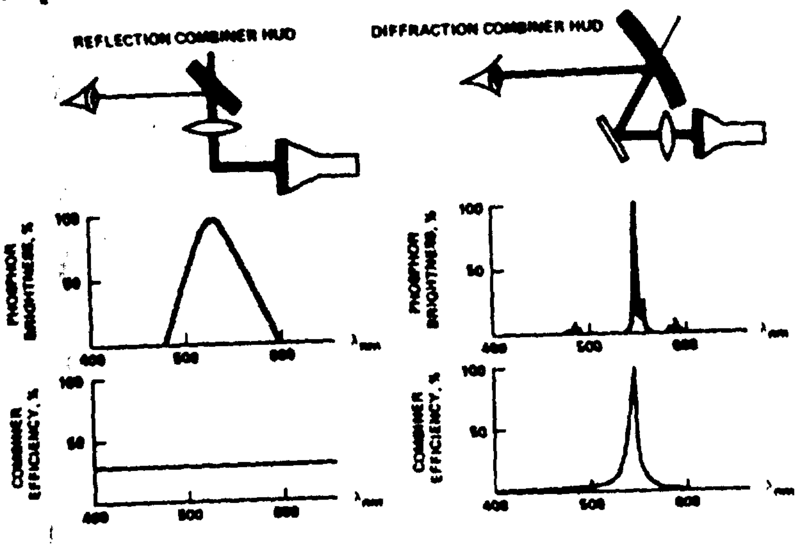
	CONVENTIONAL OPTICS HUD	DIFFRACTION OPTICS HUD
Instantaneous Field of View:	11.5° elevation 17.0° azimuth	20.0° elevation 35.0° azimuth
Transmission:	70%	85%
Reflectance (Average):	25%	80%
Symbol Brightness (max):	1,600 fL	5,000 fL
Contrast Ratio (10,000 fL ambient):	1.2	1.6
Raster Brightness:	400 fL	1,200 fL

Improved visibility of targets and terrain



DIFFRACTION COMBINER IS MORE TRANSPARENT TO THE PILOT

Improved image brightness



DIFFRACTION COMBINER IS 3 TO 4 TIMES MORE EFFICIENT

HUGHES

HUGHES AIRCRAFT COMPANY
AEROSPACE GROUPS
RADAR SYSTEMS GROUP
P.O. BOX 92426
LOS ANGELES, CA 90009

11/13/79

WIDE FIELD OF VIEW DIFFRACTION
HUD DEMONSTRATOR UNIT

A. INTERFACES:

1.	Stroke/Raster Mode Select	+5V	Logic Level
2.	X-Deflection (Stroke)	±5V	Into 75 Ohms
3.	Y-Deflection (Stroke)	±5V	Into 75 Ohms
4.	Z-Axis (Stroke)/Bright-Up	0/+2.5V	Into 75 Ohms
5.	TV Video (Raster)	EID STD RS170	1 Volt Composite Video

Can be modified for other deflection or video levels, separate sync and video.

Assumes HAC suitcase is used for LVPS; lab. supplies may be substituted.

B. OPERATING PARAMETERS

1. Writing Speed:

   Raster: Up to 30 μsec./diameter
   (~100,000 inches/sec.)

   Stroke: 250 μsec./diameter
   (~12,000 inches/sec.)

2. Deflection Bandwidth (Small Signal):

   Greater than 1.2 MHz

3. Deflection Setting Time:

   Less than 2.5 μsec.

4. Slew Rate:

   Faster Than 10 μsec./diameter
   (~300,000 inches/sec.)

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5. Video Bandwdith:

Greather than 15 MHz

6. Power (HUD + Electronics + LVPS):

60 Hz, 110V, 1Ø, 400 Watts

APPENDIX C

TEXAS INSTRUMENTS RADAR PRESENTATION

AGENDA

INTRODUCTION	GENE HARWELL
FDL/SINGER INTERESTS	GORDON BROOKINGS
AIR-TO-GROUND RADARS FOR THE 1990's	KEN KIESLING
RADAR SIGNAL PROCESSING FOR THE 1990's	JOHN GRIMM
DISCUSSION	ALL

TACTICAL AIR/GROUND SCENARIO FOR THE '90s

THE PROBLEM

- A SERIOUS DEFICIENCY CURRENTLY EXISTS IN THE USAF'S CAPABILITY TO PERFORM EFFECTIVE NIGHT/ALL-WEATHER AIR-TO-SURFACE ATTACK AGAINST MOBILE AND FIXED TARGETS

- THIS DEFICIENCY WILL BECOME WORSE IN THE FUTURE DUE TO THE COMBINED EFFECTS OF:

  EVOLVING ENEMY TECHNOLOGY
  PROJECTED THREAT INTENSITIES
  EXISTING-FORCE AGING

- THE WARSAW PACT THREAT THROUGH THE 1990 DECADE IS EXPECTED TO CONSIST OF:

  ANTI-AIRCRAFT ARTILLERY (AAA)
  SURFACE-TO-AIR MISSILES (SAMS)
  INTERCEPTOR AIRCRAFT
  RADIATION WARFARE
  ELECTRONIC WARFARE
  NUCLEAR/BIOLOGICAL/CHEMICAL (NBC) WARFARE

TACTICAL AIR/GROUND SCENARIO FOR THE '90s (CONTINUED)

THE SOLUTION

ADVANCED TACTICAL FIGHTER WITH AUTONOMOUS CAPABILITY TO DETECT, ATTACK, AND DESTROY HARD MOBILE TARGETS WITH PARTICULAR EMPHASIS ON SECOND ECHELON ARMORED FORCES DURING NIGHT AND ALL-WEATHER CONDITIONS.

AIR-TO-GROUND RADARS FOR THE 1990's

- MISSION REQUIREMENTS
- KEY RADAR CHARACTERISTICS
  - PRECISION NAVIGATION
  - TARGETING
  - SURVIVABILITY
  - DEFENSE SUPPRESSION
  - AIR-TO-AIR
  - MARITIME STRIKE
- TI DEVELOPMENTS

AIR-TO-GROUND MISSION REQUIREMENTS

PRIMARY MISSION

- DEEP/SHALLOW INTERDICTION AND CLOSE AIR SUPPORT
  - PRECISION NAVIGATION
  - TARGET ACQUISITION
  - SURVIVABILITY

SECONDARY MISSIONS

- DEFENSE SUPPRESSION - EMITTER LOCATION AND DESTRUCTION
- AIR-TO-AIR - SELF DEFENSE
- OCEAN CONTROL - MARITIME STRIKE

MISSION PROFILES

- PRIMARY - LOW LEVEL HIGH SPEED
- SECONDARY - EXCURSIONS TO HIGH ALTITUDE PROFILES

TARGETS

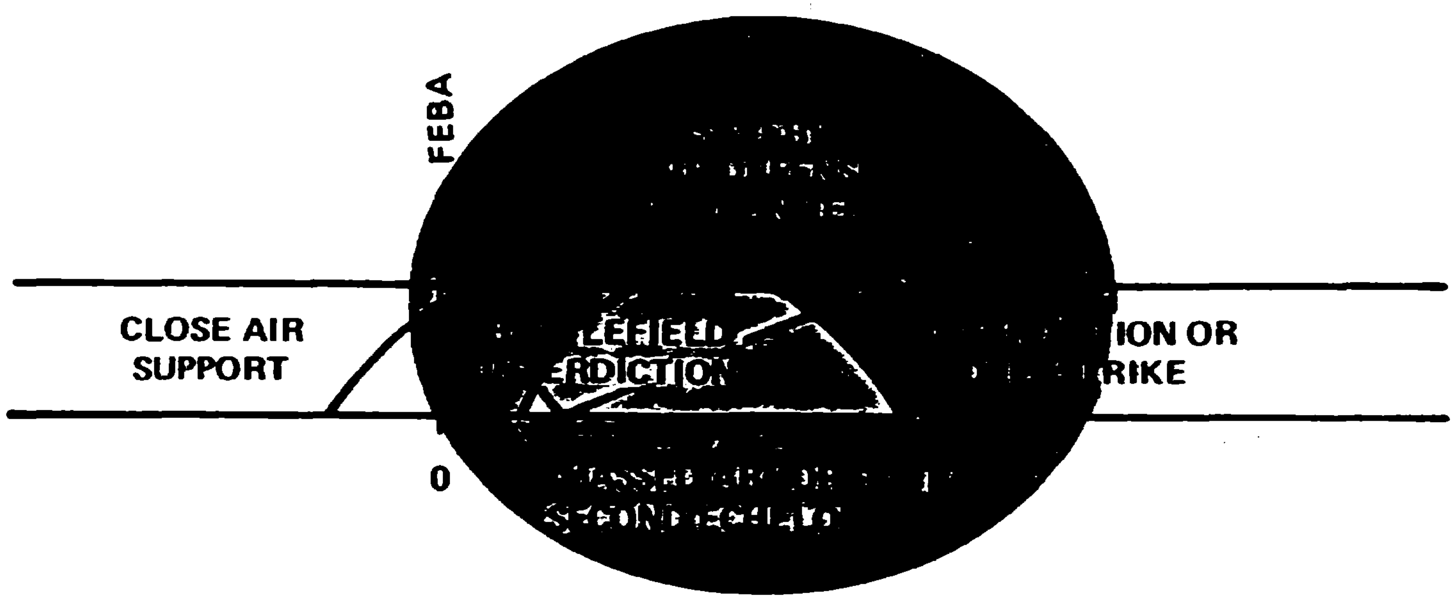
- PRIMARY - MOBILE AND FIXED TANKS, APC, TRUCKS, AIR DEFENSE UNITS
- SECONDARY - AIRFIELDS, BRIDGES, POL FACILITIES, FIXED AIR DEFENSE UNITS, SHIPS

AIR-TO-GROUND MISSION REQUIREMENTS (CONTINUED)

GENERAL

- ALL-WEATHER, 10 MM/HR RAIN
- ECCM FEATURES COMPATIBLE WITH EASTERN EUROPE ECM THREAT
- AUTONOMOUS OPERATION WITH COOPERATIVE STRIKE CAPABILITY
- EXISTING AND FUTURE WEAPONS
- LOW PROBABILITY OF INTERCEPT
- NUCLEAR ROLE COMPATIBILITY

AIR-TO-GROUND MISSION OPERATING ZONES



KEY AVIONICS

RADAR	TERRAIN FOLLOWING
	TARGETING
	NAVIGATION UPDATE
FLIR	ACQUISITION
	TRACKING/DESIGNATION
	LOOK-BACK
	> MACH 1 COMPATIBILITY
NAVIGATION	AUTONOMOUS
	GPS
	ELECTRONIC GRIDS
DISPLAYS/CONTROLLS	INTEGRATION
	AUTOMATION

DEVELOPMENT STATUS

- EQUIPMENT AVAILABLE OR IN DEVELOPMENT

  FLIR

  NAVIGATION

  DISPLAYS

- SUITABLE RADAR EQUIPMENT IS NOT AVAILABLE TODAY AND WILL REQUIRE A MAJOR DEVELOPMENT ACTIVITY

KEY AIR-TO-GROUND RADAR CHARACTERISTICS

MODES/FUNCTION	CAPABILITY	COMMENTS
DBS	15 METER RANGE RES 10:1,20:1 BEAMSPLITTING	TARGET AREA LOCATION CUE FOR HIGH RES MODES
GMTI/GMTT	15 METER RANGE RES 10:1.20:1 BEAMSPLITTING	SIMULATANEOUS DBS FOR CONTEXTUAL LOCATION, ARRAY RECOGNITION
SPOT LIGHT MAP	15 X 15 M RES	PRECISION NAV, LARGE TARGET DETECTION
	3 X 3 M RES	SMALL TARGET DETECTION SLOW MOVING TARGET DETECTION
AIR/AIR	LOW/MED/HIGH PRF 30 METER RANGE RES 10:1 BEAMSPLITTING SPARROW COMPATIBLE	COHERENT SIDELOBES DISCRIMINANT DUAL MODE TRANSMITTER BEAMSPLITTING FOR RAID ASSESSMENT
COVERT, TARGET IDENTIFICATION	100 TO 500 MHz BANDWIDTH PROGRAMMABLE POWER	

PRECISION NAVIGATION

REAL BEAM MAPPING

HIGH RESOLUTION MAPPING

PRECISION TARGET LOCATION

VELOCITY MEASUREMENT

RADAR NAVIGATION REQUIREMENTS

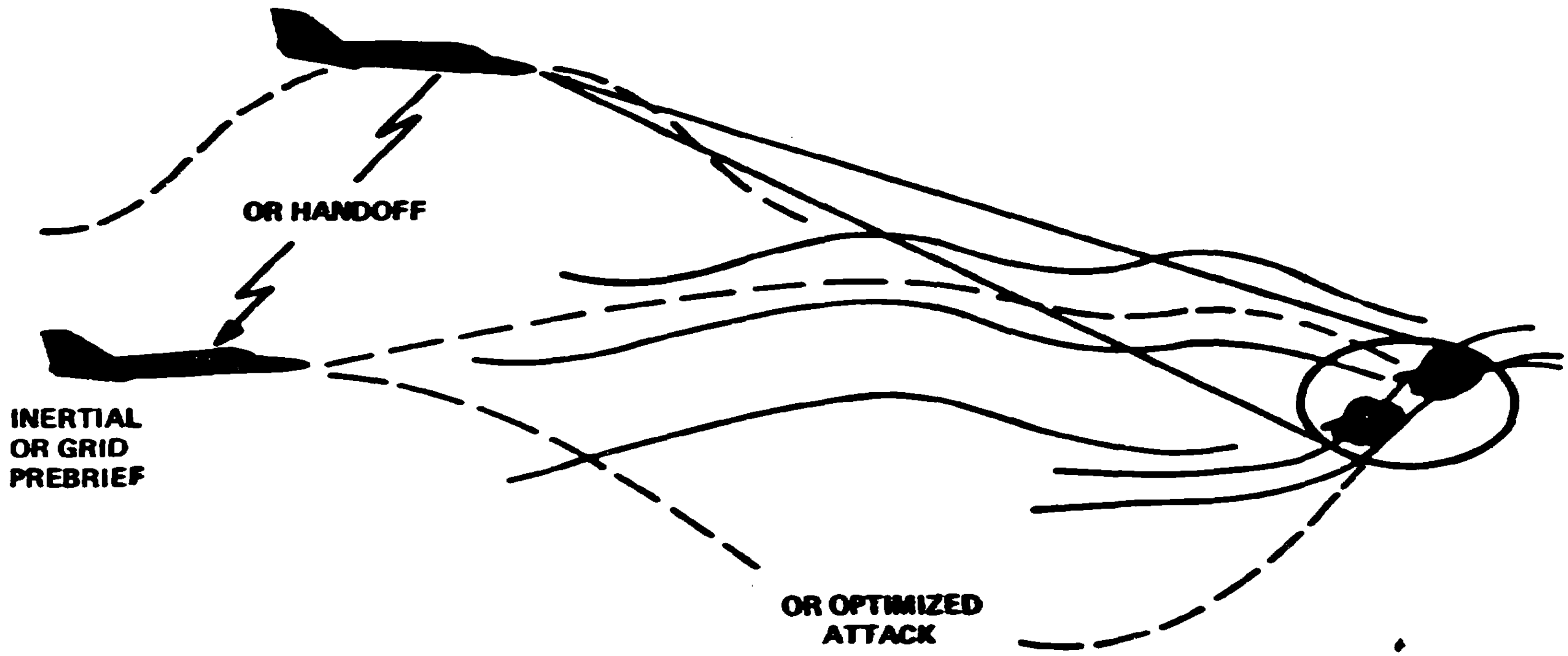
REAL BEAM MAPPING - WIDE AREA FAST SCAN GROUND MAP COMPLEMENTED WITH GROUND STABILIZED PATCH, AZIMUTH MRI, HEIGHT FINDING, AND BEACON CAPABILITIES FOR NAVIGATION

DOPPLER BEAM SHARPENING - MEDIUM RESOLUTION GROUND MAP FOR TARGET AREA LOCATION, LARGE TARGET IDENTIFICATION, AND IMPROVED SEPARATION AND CONTEXTUAL DISPLAY OF GROUND MOVING TARGETS

SPOTLIGHT IMAGE - HIGH RESOLUTION SAR SPOTLIGHT GROUND MAP FOR SMALL TARGET DETECTION, TARGET DESIGNATION, PRECISION NAVIGATION POSITION UPDATE, IMU SUPERVISION, BOMB DAMAGE ASSESSMENT, AND CORRELATION OF DIGITALLY STORED DMA TERRAIN DATA

VELOCITY MEASUREMENT - RADAR DOPPLER-VELOCITY MEASUREMENT OF AIRCRAFT GROUND SPEED FOR PRECISION NAVIGATION VELOCITY UPDATE.

PRECISION NAVIGATION FOR PREBRIEFED TARGETS, TARGET HANDOFFS AND TARGETS OF OPPORTUNITY



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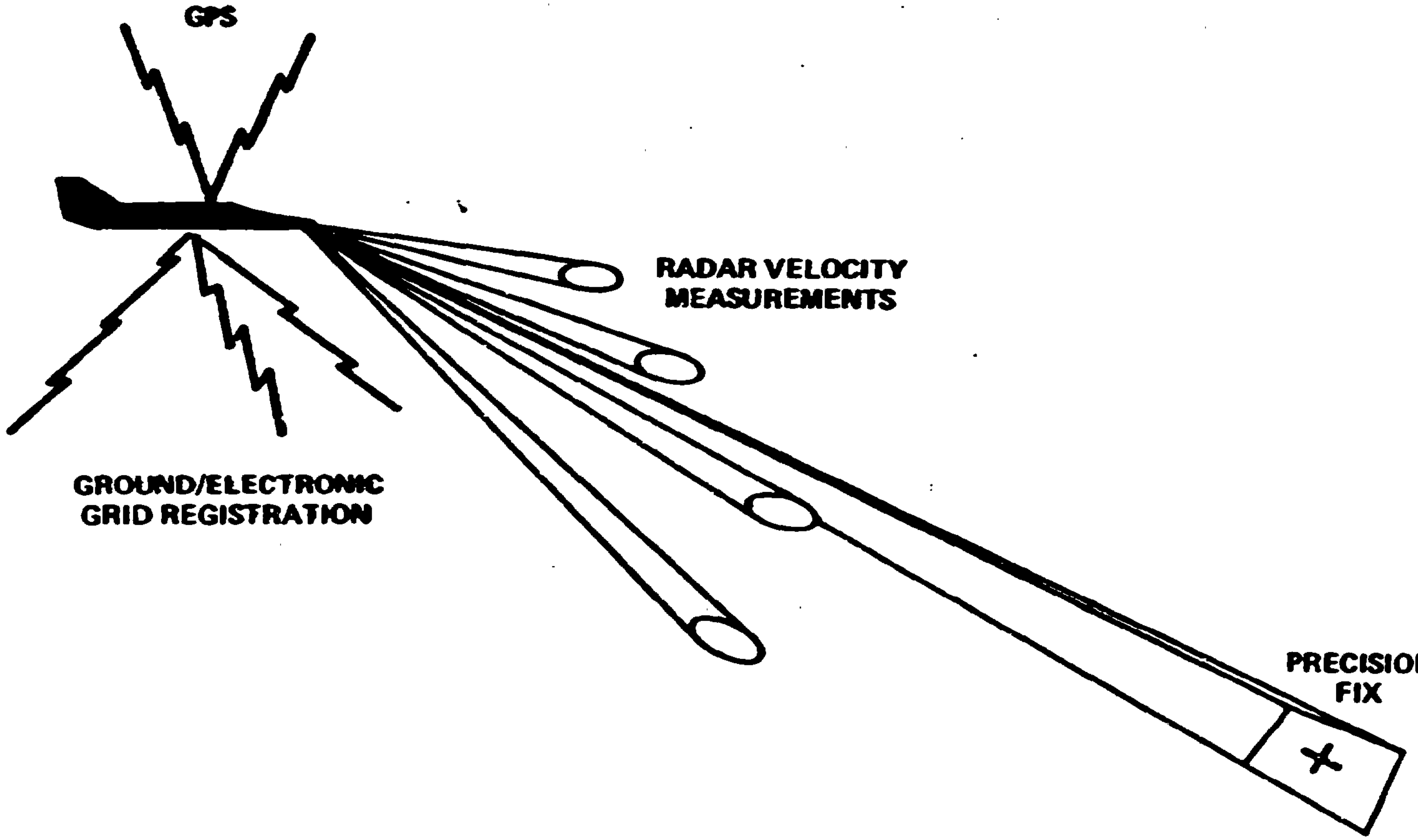
PRECISION NAVIGATION



PRECISION TARGET LOCATION

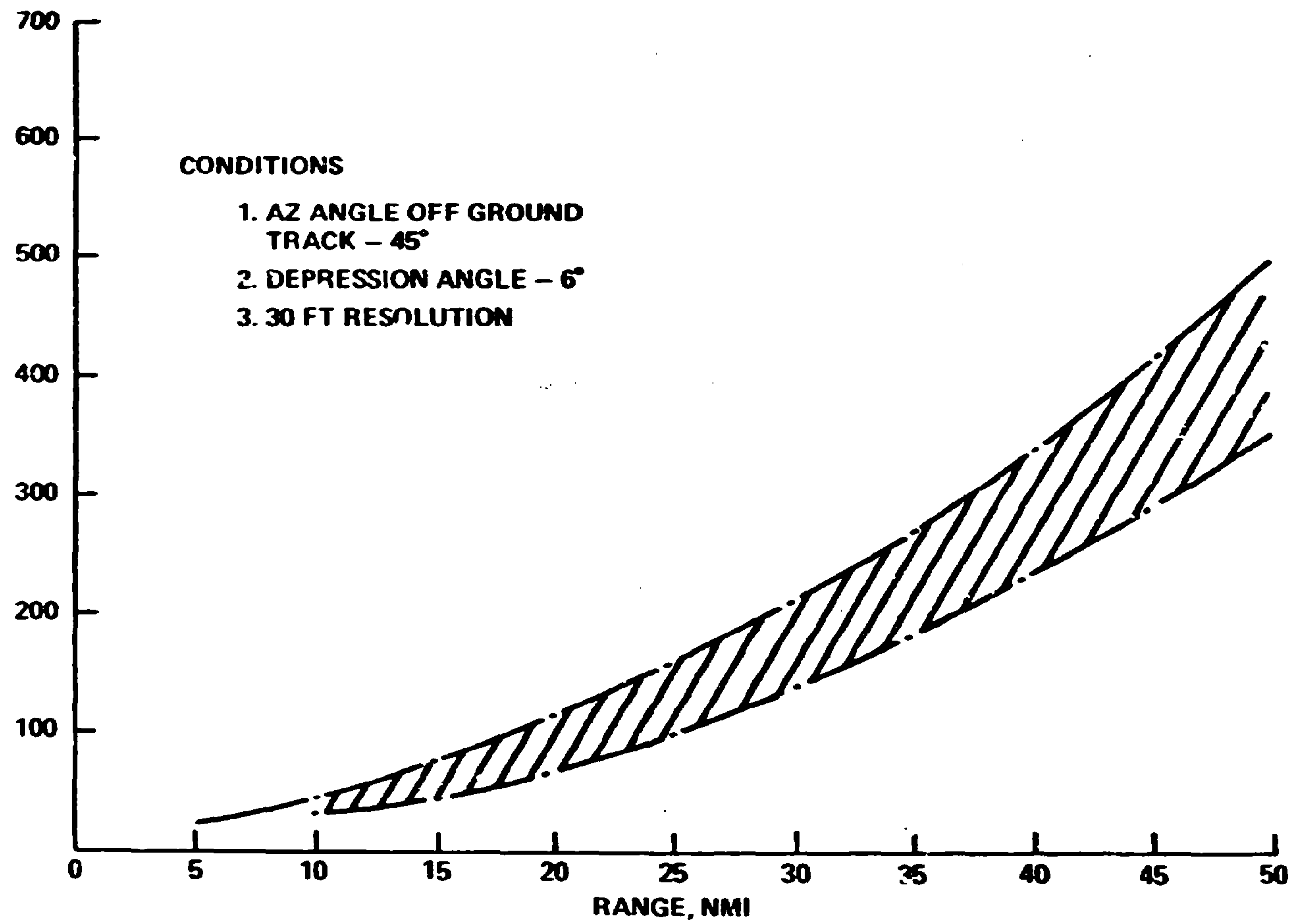
KEY RADAR ELEMENTS

- ANTENNA POSITION IN INERTIAL COORDINATES
- RADAR VELOCITY MEASUREMENTS
- HIGH RESOLUTION SAR TARGET DETECTION AND TRACK
- DMA TERRAIN DATA STORAGE AND CORRELATION

APPLICATIONS

- MANUAL AND AUTOMATED PRECISION NAVIGATION UPDATES
- TACTICAL FLIGHT CONTROL AND MANEUVER PLANNING
- WEAPON DELIVERY AT EXTENDED RANGE AND IMPROVED ACCURACY
- TARGET LOCATION HANDOFF VIA INERTIAL/GROUND/ELECTRONIC GRID REGISTRATION

POSITION FIX ERROR VS RANGE FOR HIGH RESOLUTION MAP MODE



TARGETING

FAST MOVING TARGETS

SLOW MOVING TARGETS

SMALL TACTICAL TARGETS

RADAR TARGETING REQUIREMENTS

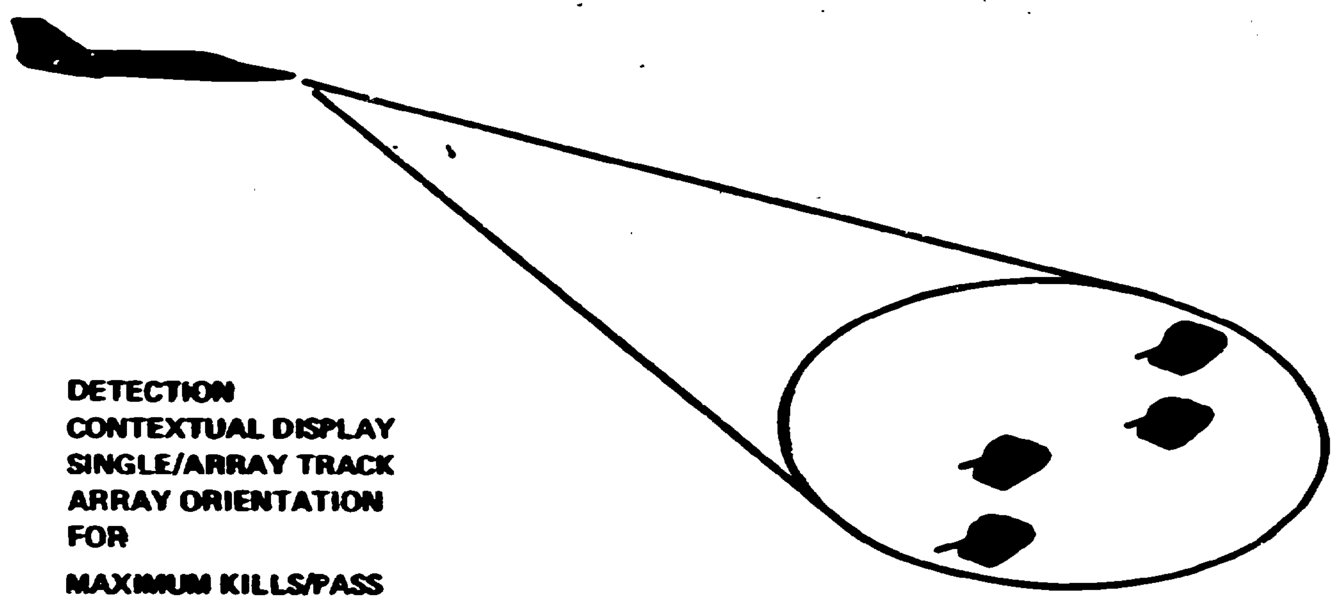
GROUND MTI/MTT	-	WIDE AREA FAST SCAN GMTI SURVEILLANCE WITH SIMULTANEOUS REAL BEAM GROUND MAP FOR FAST MOVING TARGET DETECTION AND SINGLE TARGET RANGE/ANGLE TRACK. REAL BEAM RESOLUTION SUITABLE FOR DETECTING FAST MOVING TACTICAL TARGETS CLEAR OF MAINBEAM CLUTTER. SINGLE CHANNEL PROCESSING FOR SURVEILLANCE.
GMTI/GMTT/DBS MAP	-	SECTOR SCAN GMTI WITH SIMULTANEOUS DBS GROUND MAP FOR FAST MOVING TARGET DETECTION, TARGET ARRAY ORIENTATION, AND TARGET RELOCATION/ CONTEXTUAL DISPLAY. MEDIUM RESOLUTION BEAMSPLITTING REQUIRED FOR ARRAY ORIENTATION, TARGET RELOCATION AND SINGLE TARGET/ARRAY CENTROID RANGE/ANGLE TRACK. DUAL CHANNEL PROCESSING REQUIRED.

KDK, 01-931, 2/25/80

RADAR TARGETING REQUIREMENTS (CONTINUED)

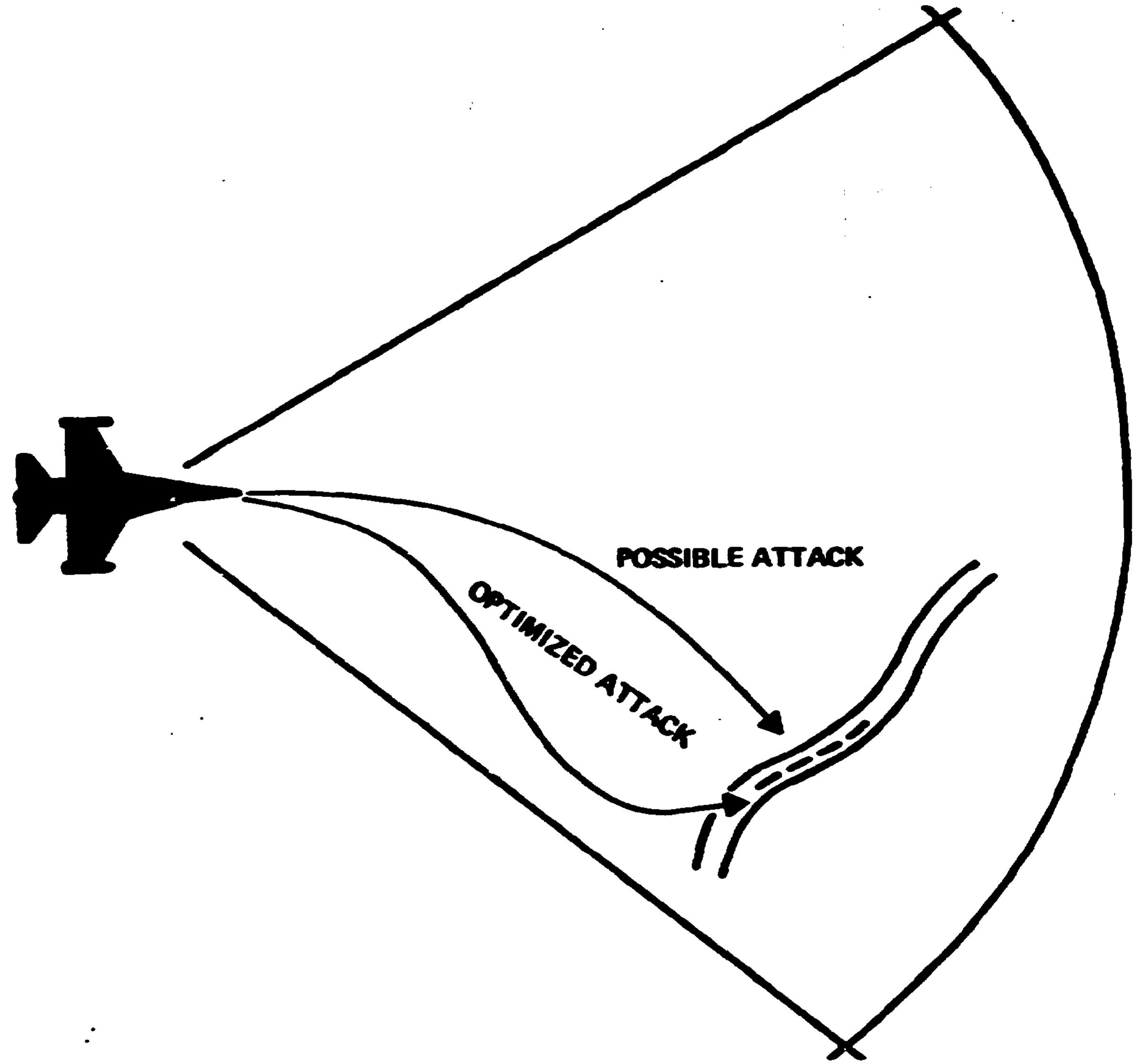
SPOTLIGHT IMAGE	-	HIGH RESOLUTION SAR SPOTLIGHT GROUND MAP FOR FIXED AND SLOW MOVING TACTICAL TARGET DETECTION AND SLOW MOVING TARGET RELOCATION. HIGH RESOLUTION REQUIRED FOR DETECTION OF SMALL TACTICAL TARGETS IN MAINBEAM CLUTTER. DUAL CHANNEL PROCESSING REQUIRED.
AIR/GROUND RANGING	-	ELEVATION MONOPULSE BORESIGHT RANGING AGAINST DISTRIBUTED AND POINT TARGETS FOR RADAR BOMBING/WEAPON DELIVERY.
GROUND TARGET TRACK	-	RANGE/ANGLE TRACK OF LARGE FIXED AND MOVING GROUND TARGETS FOR RADAR BOMBING/WEAPON DELIVERY.
TARGET CLASSIFICATION	-	HIGH RESOLUTION RANGE/DOPPLER IMAGE PROFILES FOR TACTICAL TARGET CLASSIFICATION

MOVING TARGETS

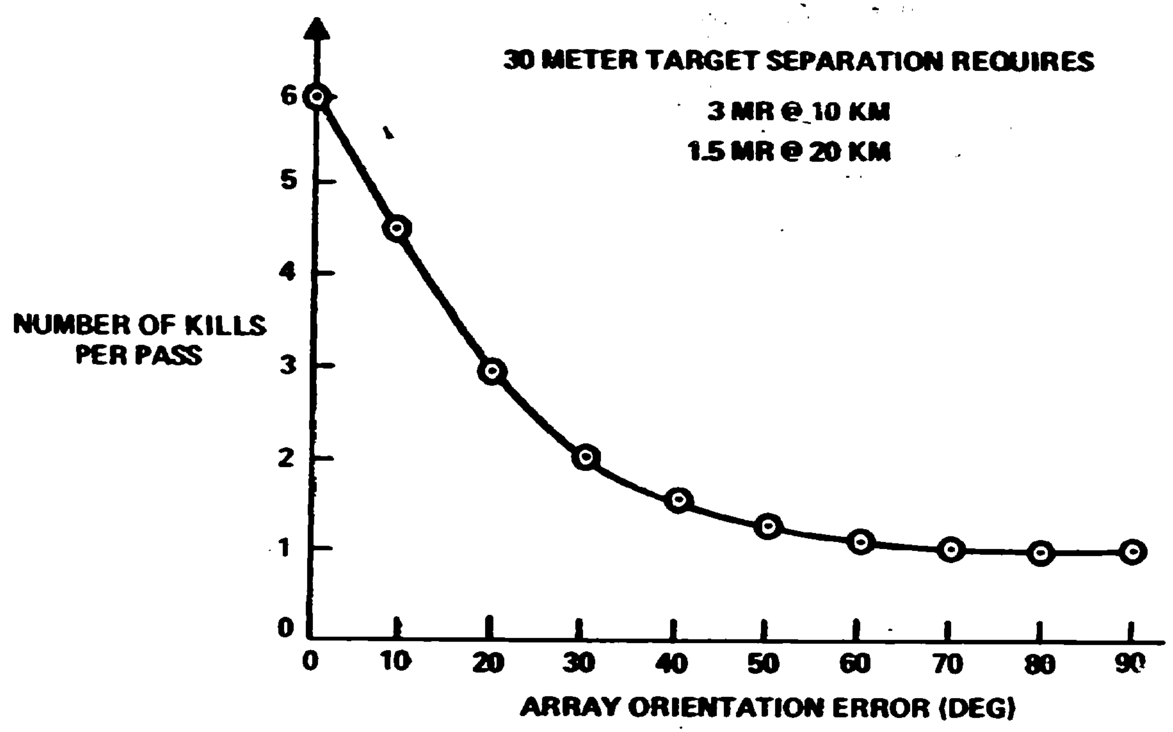


DETECTION
CONTEXTUAL DISPLAY
SINGLE/ARRAY TRACK
ARRAY ORIENTATION
FOR
MAXIMUM KILLS/PASS

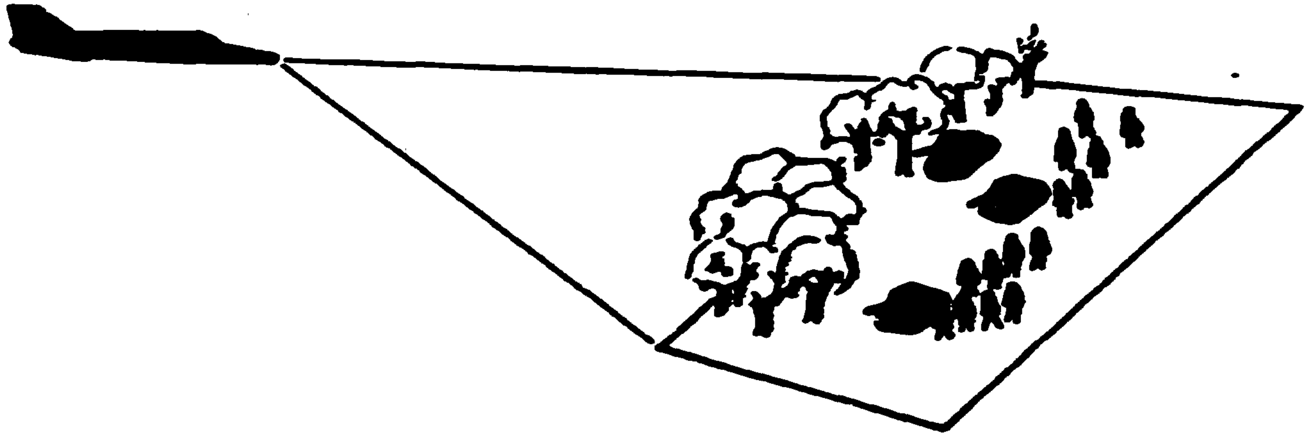
MAXIMIZING KILLS/PASS



EFFECTS OF ARRAY ORIENTATION ON THE NUMBER OF KILLS PER PASS

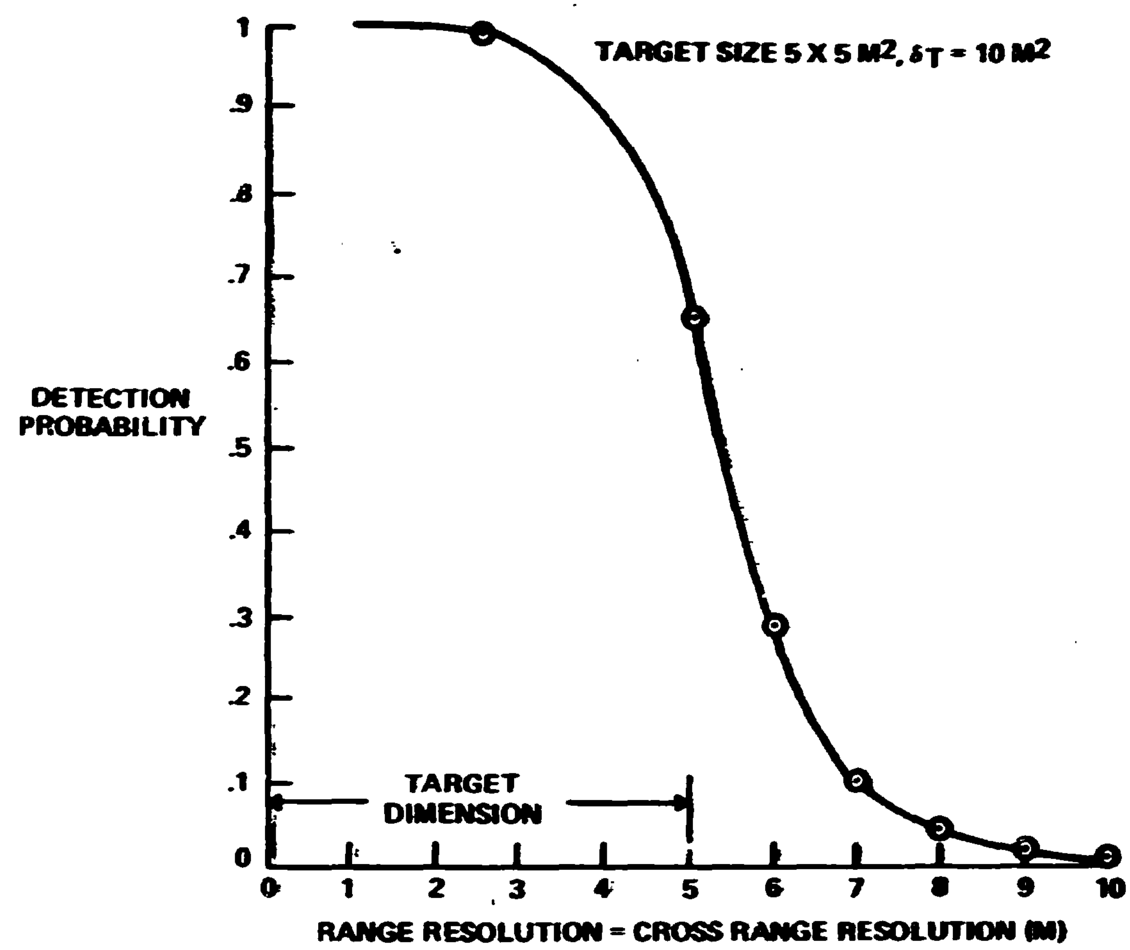


SLOW MOVING AND FIXED TACTICAL TARGETS



DEMANDS HIGHER RESOLUTION FOR
DETECTION OF TARGETS IN CLUTTER

DETECTION PROBABILITY BASED ON SIGNAL-TO-CLUTTER RATIO



SURVIVABILITY

AUTOMATIC TERRAIN FOLLOWING

COVERT/STEALTH OPERATION

EFFECTIVE ECCM

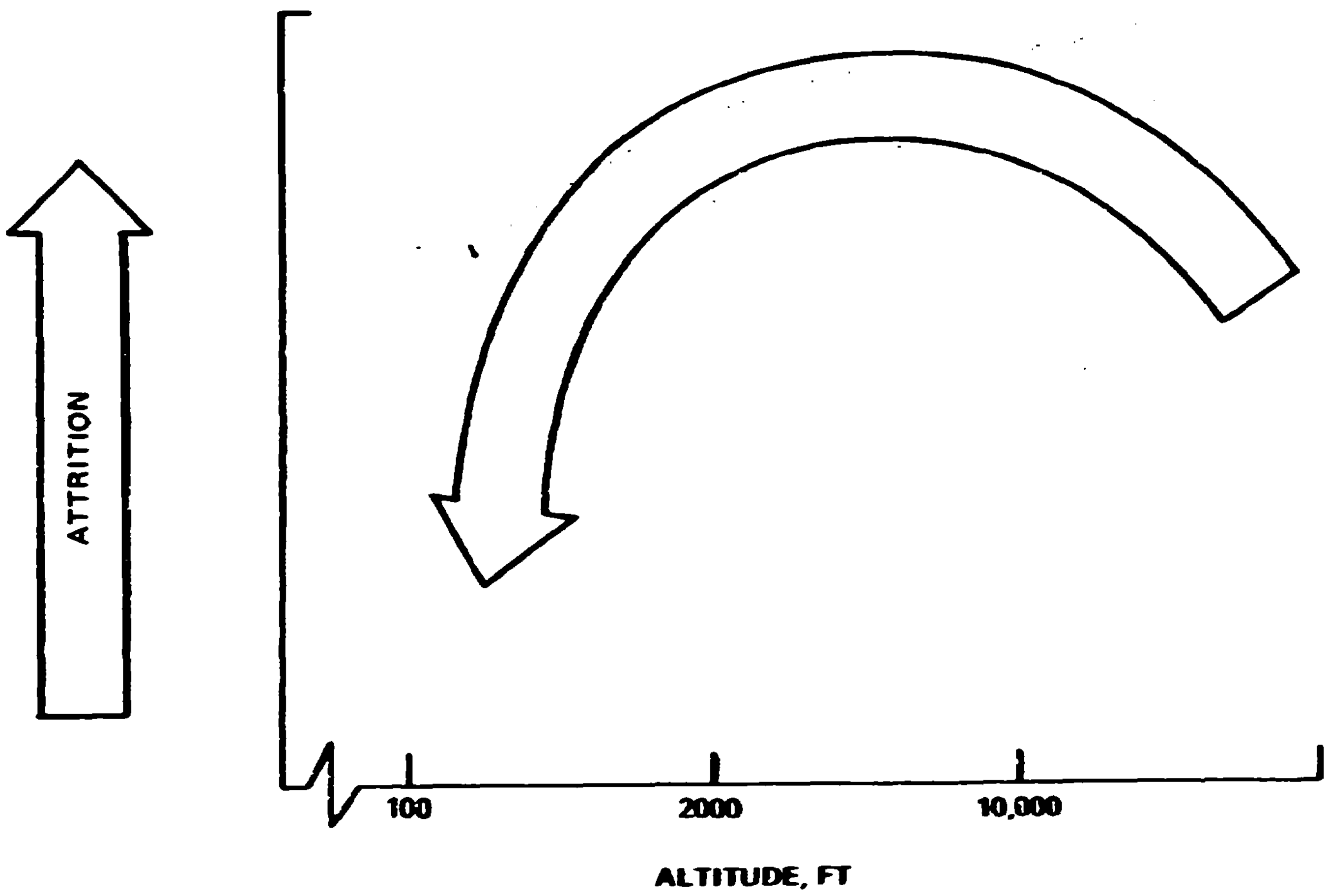
AUTOMATIC TERRAIN FOLLOWING FOR SURVIVABILITY

AIR DEFENSE SYSTEMS

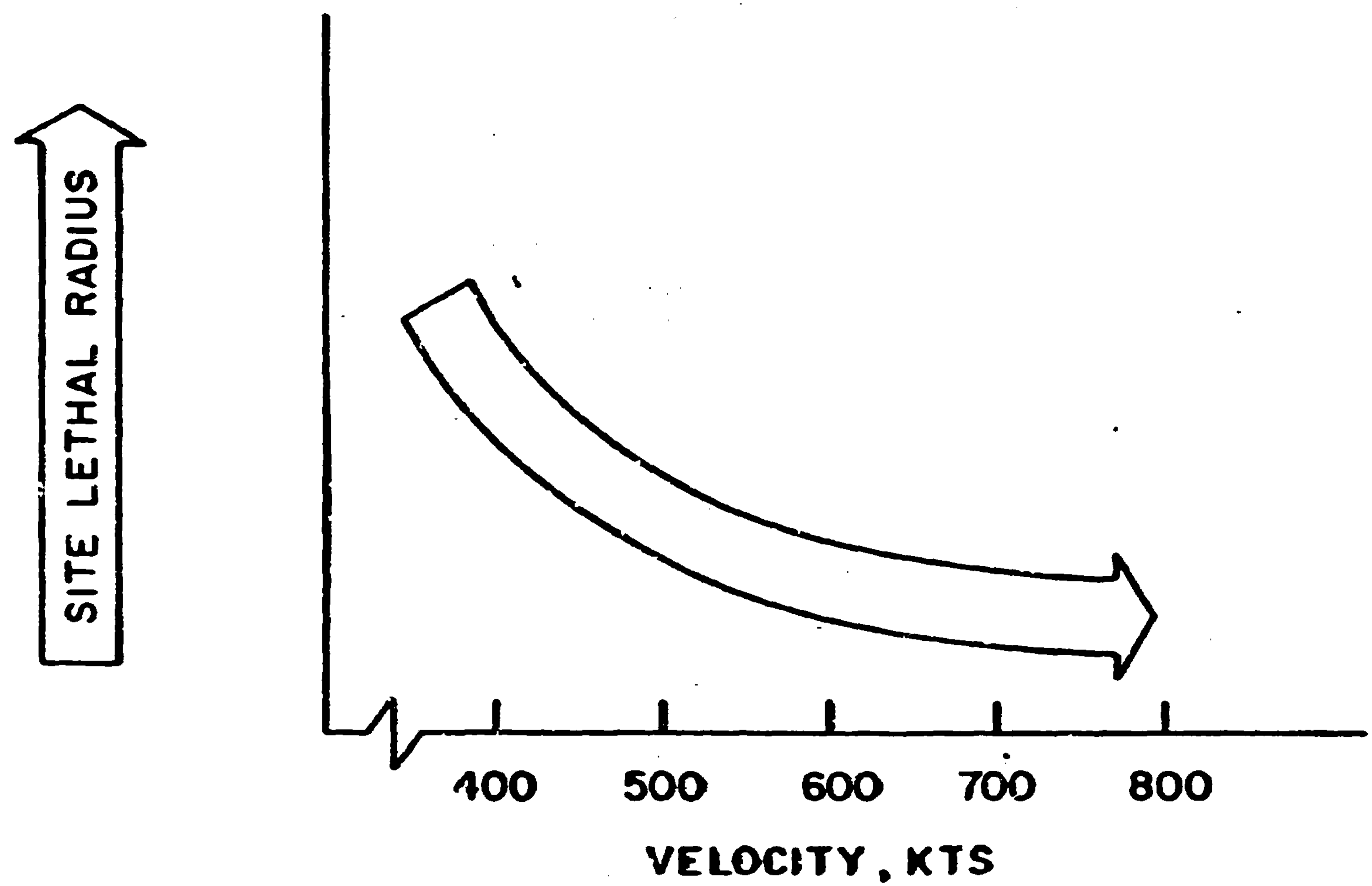
THREAT	ACQUISITION	FIRE CONTROL
GUNS ZSU-23-4 S-60	RADAR, OPTICS, TV	OPTICS
IR MISSILES SA-7 SA-9	VISUAL	INFRA-RED
RADAR MISSILES SA-4 SA-6 SA-8	RADAR, OPTICS, TV	RADAR/COMMAND

ALTITUDE EFFECTS

TACTICAL PENETRATION/STRIKE MISSION

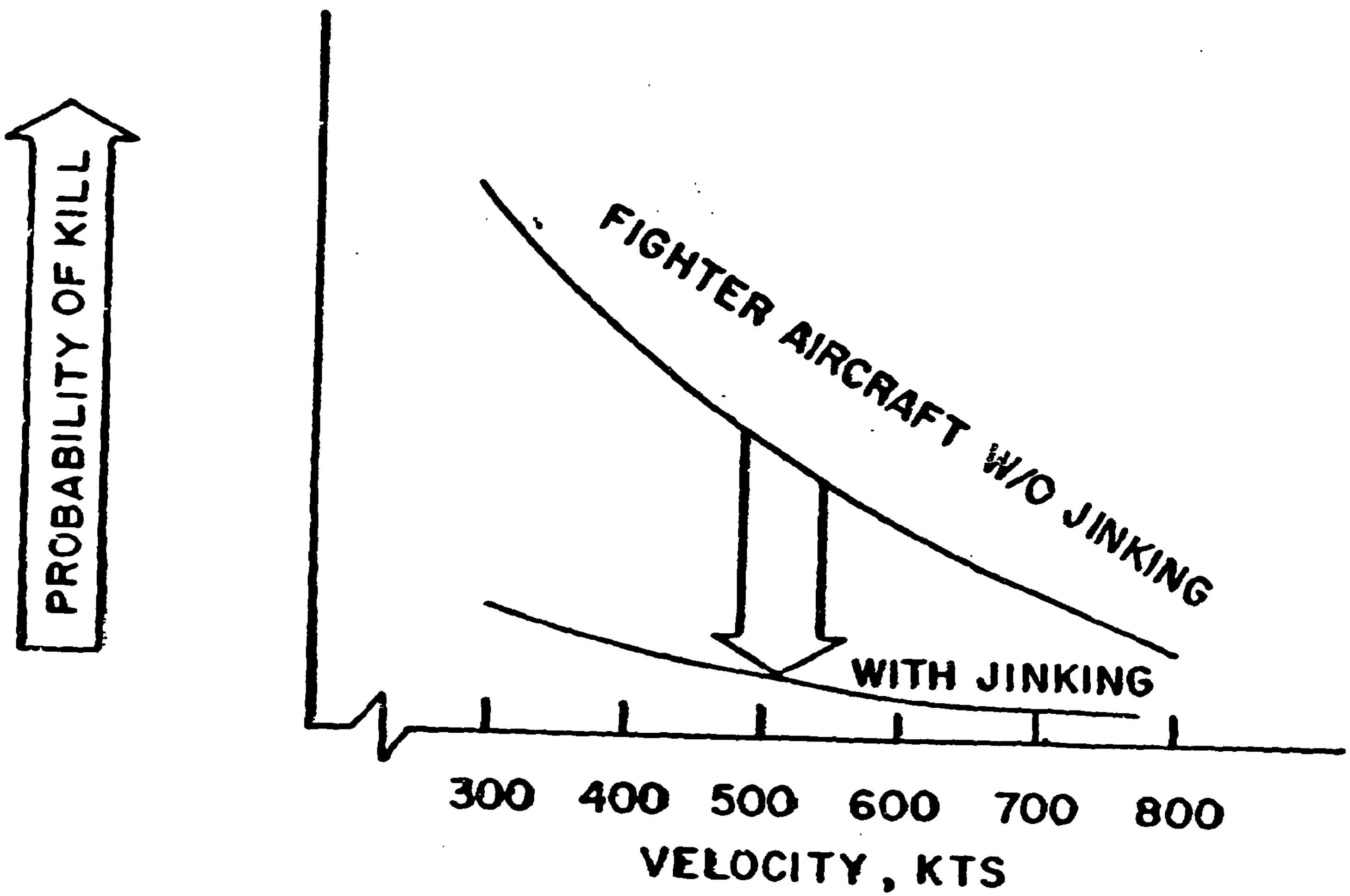


VELOCITY LEVERAGE



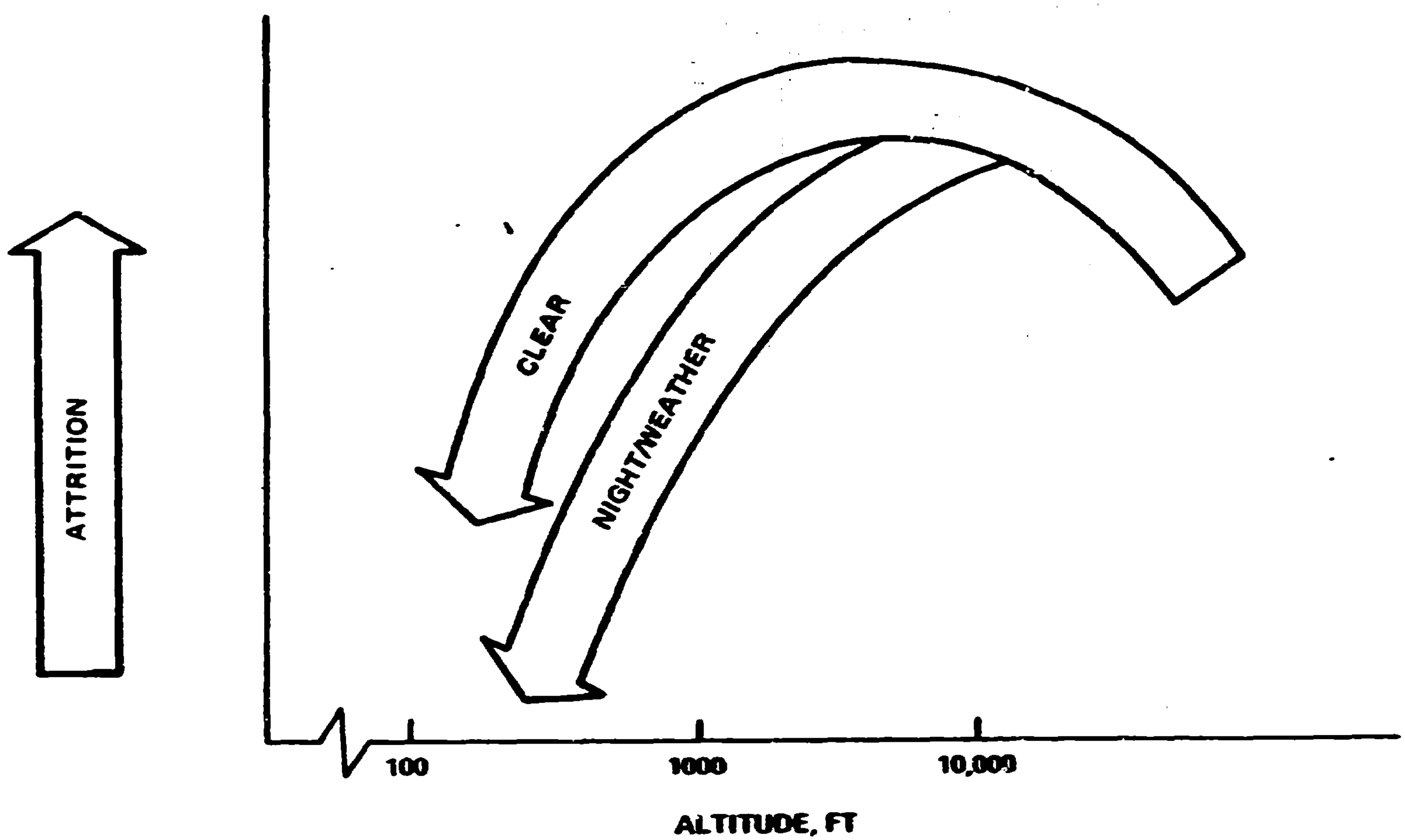
MANEUVER IMPACT

ZSU-23-4 EFFECTIVENESS



RADAR ADVANCED DEVELOPMENT

NIGHT-WEATHER IMPROVEMENT



EQUIPMENT GROUP

0190171.0

ADVANCED TF REQUIREMENTS

LATERAL MANEUVERS

- PROGRAMMED HI-G LATERAL MANEUVERS (JINKING) DURING AUTOMATIC TERRAIN FOLLOWING TO REDUCE LETHALITY OF ENEMY AIR DEFENSE.
- BROAD AZIMUTH COVERAGE, HIGH UPDATE RATES, AND TERRAIN STORAGE REQUIRED FOR SAFETY AND FULL TF PERFORMANCE CAPABILITY.
- PERSPECTIVE HORIZONTAL SITUATION DISPLAY DESIRED TO OPTIMIZE LATERAL MANEUVERS FOR MAXIMUM TERRAIN MASKING.

ECCM FEATURES

- ECCM PERFORMANCE MUST BE COMPATIBLE WITH THE PROJECTED EASTERN EUROPE ECM THREAT ENVIRONMENT.
- IMPROVED JAMMER SUPPRESSION IS REQUIRED FOR EFFECTIVE TF OPERATION AGAINST THE PROJECTED ECM THREAT.

NIGHT/ALL-WEATHER OPERATION

- ADVANCED TF SENSORS MUST PROVIDE FULL TF PERFORMANCE CAPABILITY FOR NIGHT/ALL-WEATHER OPERATION AT MINIMUM SET CLEARANCE AND HIGH VELOCITY.
- ALL-WEATHER OPERATION MUST INCLUDE RAINFALL RATES UP TO 10 MM/HR AND ZERO-VISIBILITY FOG AND CLOUD CONDITIONS.

COVERT/STEALTH OPERATION

OBJECTIVE

APPLY ADVANCED LPI WAVEFORM DESIGN AND SIGNAL PROCESSING TECHNOLOGY TO DENY DETECTION BY INTERCEPT RECEIVERS TO MINIMUM POSSIBLE RANGE.

TECHNIQUES

MINIMIZE POWER SPECTRAL DENSITY

- MINIMUM PEAK POWER
- WIDE BANDWIDTH WAVEFORMS
- LARGE TIME-BANDWIDTH PULSE COMPRESSION
- BROADBAND FREQUENCY AGILITY/DIVERSITY

MINIMIZE ANTENNA SIDELOBES

DMA TERRAIN DATA STORAGE

- TERRAIN CORRELATION FOR TACTICAL FLIGHT CONTROL
- PRECISION NAVIGATION
- SELECTIVE UPDATES FOR MINIMUM RADIATION

RETAIN PERFORMANCE

- MATCHED FILTER PROCESSING
- LARGE PULSE COMPRESSION GAIN
- MAXIMUM SIGNAL PROCESSING INTEGRATION GAIN
- HIGH AVERAGE POWER

EFFECTIVE ECCM FEATURES

GENERAL

- JAMMER DETECTION AND WARNING (SNIFF)
- JAMMER AVOIDANCE (PREPULSE/SPOOF)

TRANSMITTER

- BROADBAND RANDOM FREQUENCY AGILITY
- RANDOM PRF JITTER
- DUAL MODE PEAK POWER
- WAVEFORM DIVERSITY
- HIGH ENERGY PULSE WAVEFORMS
- COHERENT OPERATION

ANTENNA

- HIGH GAIN
- LOW SIDELOBES
- AZIMUTH/ELEVATION MONOPULSE
- VARIABLE POLARIZATION
- GUARD CHANNEL
- BROADBAND PASSIVE DF INTERFEROMETER

EFFECTIVE ECCM FEATURES (CONTINUED)

RECEIVER/EXCITER

- COHERENT OPERATION
- MONOPULSE PROCESSING
- GUARD CHANNEL PROCESSING
- DUAL CONVERSION
- RF AND IF IMAGE REJECTION
- LARGE DYNAMIC RANGE
- PULSE COMPRESSION
- CFAR THRESHOLDING
- STC/AGC DIVERSITY

SIGNAL PROCESSING

- DIGITAL PROCESSING
- DIGITAL PULSE COMPRESSION
- DOPPLER PROCESSING
- M:N COINCIDENCE DETECTION
- KALMAN FILTER TRACKING
    - RANGE RATE TRACKING
    - ACCELERATION LIMITING
    - PASSIVE/ACTIVE TRACKING
    - PASSIVE RANGE ESTIMATION
    - ANGLE-ON-JAM TRACKING
    - INERTIAL COAST

DEFENSE SUPPRESSION

PASSIVE SEARCH AND THREAT CLASSIFICATION

PASSIVE ACQUISITION AND TRACK

RANGE ESTIMATION

ACTIVE ACQUISITION AND TRACK

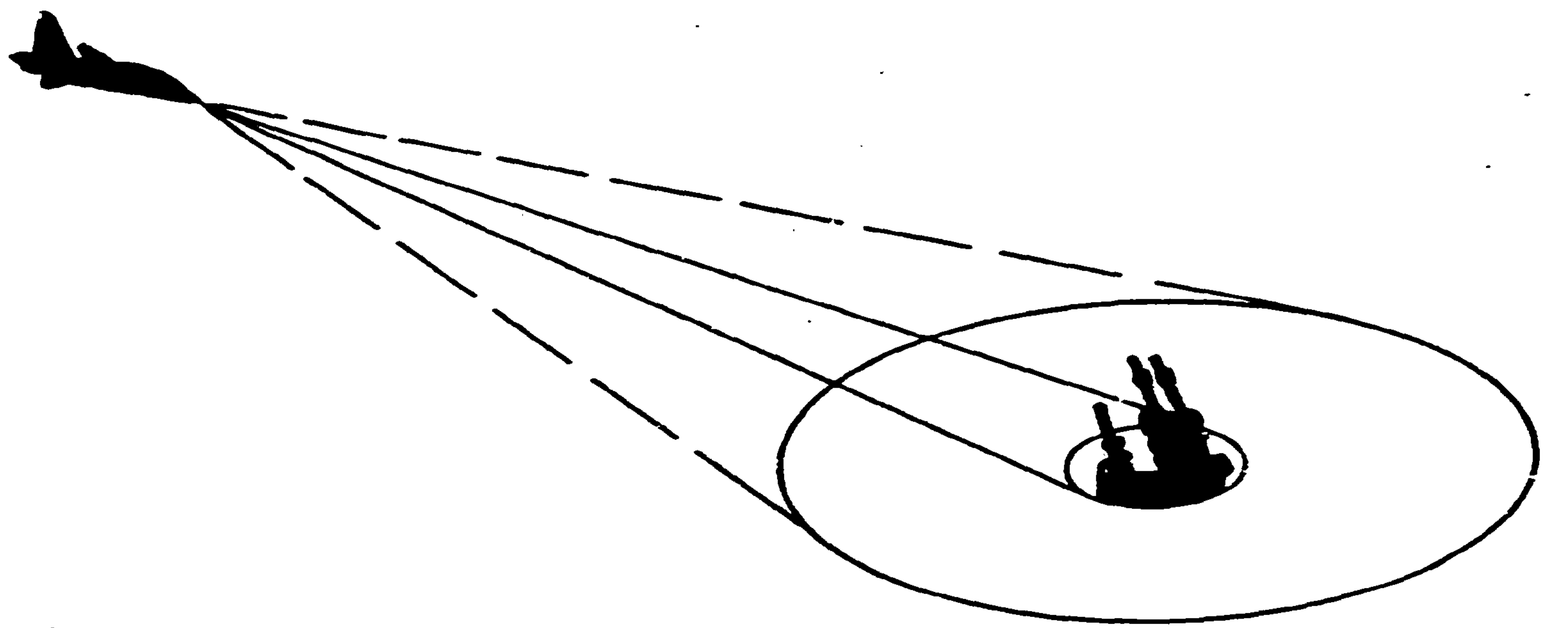
DEFENSE SUPPRESSION REQUIREMENTS

PASSIVE SEARCH	-	WIDE ANGLE PASSIVE SEARCH AND CLASSIFICATION OF EMITTER SIGNATURES IN THREAT FREQUENCY BAND WITH CAPABILITY FOR SEARCH ABOUT A PREDESIGNATED INERTIAL AIM-POINT.
PASSIVE ACQ. AND TRACK	-	PRECISION DF INTERFEROMETER AZIMUTH/ELEVATION ANGLE TRACKING OF EMITTER WITH INERTIAL BEAM POINTING AFTER EMITTER SHUT-DOWN.
RANGE ESTIMATION	-	PASSIVE RANGING, ACTIVE AIR-TO-GROUND BORESIGHT RANGING AND TARGET RANGING ALONG A PREDESIGNATED INERTIAL AIM-POINT.

DEFENSE SUPPRESSION REQUIREMENTS (CONTINUED)

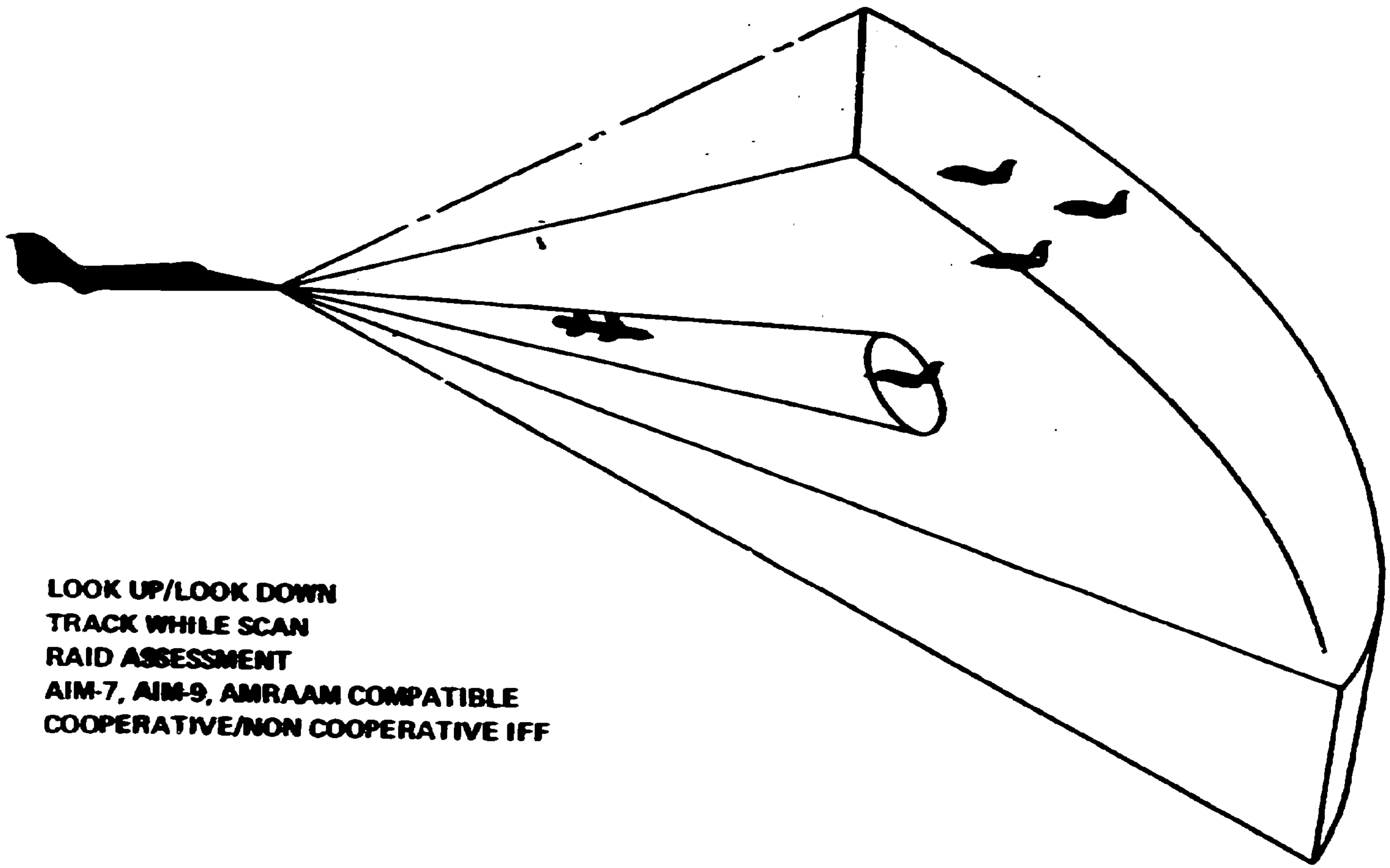
ACTIVE ACQUISITION	- ACTIVE RADAR SIGNAL ANALYSIS TO DETECT THREAT RADAR SCAN MODULATION CHARACTERISTICS AND RADAR CROSS-SECTION DISTRIBUTION. MONOPULSE AND DBS TECHNIQUES TO ACQUIRE TARGETS LOCATED ON PASSIVE/ACTIVE ANTENNA BORESIGHT.
ACTIVE TRACKING	- AZIMUTH AND ELEVATION MONOPULSE ANGLE TRACKING AND RANGE TRACKING OF EMITTERS USING FREQUENCY AGILITY OR COHERENT DBS PROCESSING. INERTIAL-RATE TRACKING THROUGH TARGET FADES OR REGIONS OF TARGET MASKING.

PASSIVE-ACTIVE TARGET ACQUISITION FOR DEFENSE SUPPRESSION/AVOIDANCE



IDENTIFICATION	•	PASSIVE CHARACTERIZATION OF SPECTRAL SIGNATURE
LOCATION	•	PASSIVE DF, HANDOFF FOR ACTIVE TRACK
	•	ACTIVE SEARCH, RCS CHARACTERIZATION
	•	SAR TARGET ACQUISITION

AIR-AIR



- LOOK UP/LOOK DOWN
- TRACK WHILE SCAN
- RAID ASSESSMENT
- AIM-7, AIM-9, AMRAAM COMPATIBLE
- COOPERATIVE/NON COOPERATIVE IFF

TARGET CLASSIFICATION

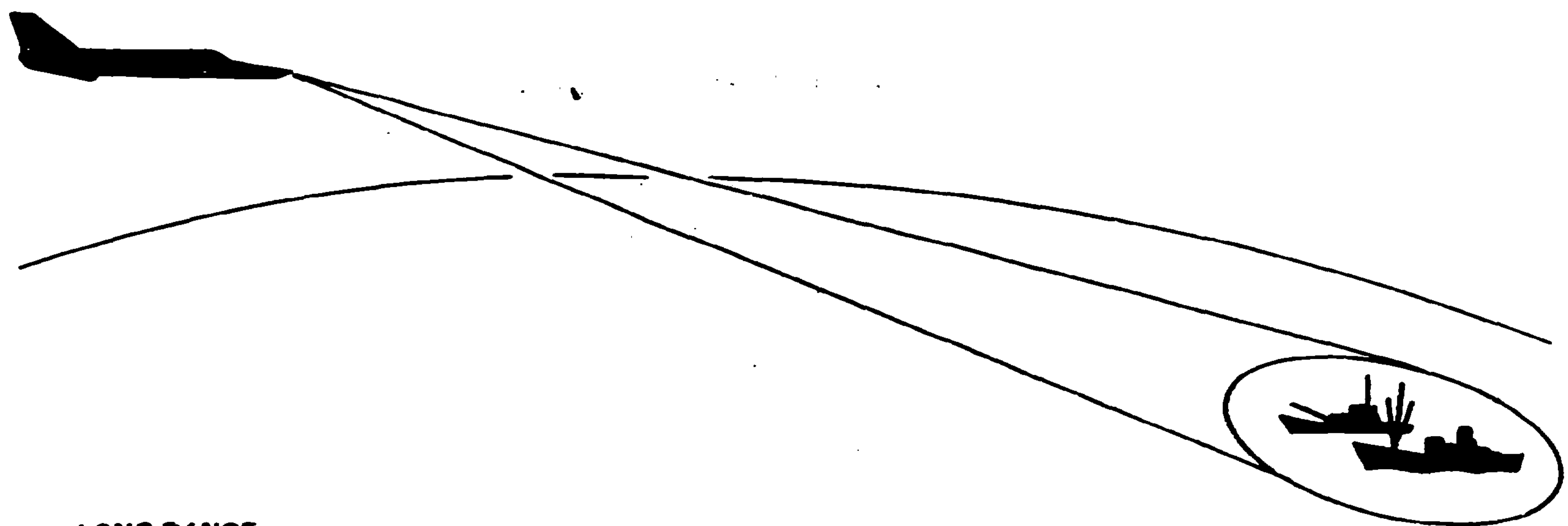
OBJECTIVES

NONCOOPERATIVE IFF AND TARGET CLASSIFICATION BASED ON HIGH RESOLUTION TWO-DIMENSIONAL RANGE/DOPPLER IMAGING OF AIRBORNE MOVING TARGETS

TECHNIQUES

- TRACK MODE USED TO ESTABLISH RANGE RATE AND HEADING ESTIMATES
- RANGE/DOPPLER IMAGE PROCESSING MODE ENTERED FROM TRACK MODE
- RESOLUTION IN RADIAL DIMENSION DERIVED BY RANGE SAMPLING
  - RANGE STABILIZATION REQUIRED
  - RANGE RESOLUTION LESS THAN 0.5M DESIRABLE
- RESOLUTION IN CROSS-RANGE DIMENSION DERIVED BY DOPPLER PROCESSING
  - DOPPLER STABILIZATION AND FOCUSING REQUIRED
  - DOPPLER RESOLUTION LESS THAN 2.0Hz DESIRABLE

MARITIME STRIKE



LONG RANGE
DETECTION WITH
CLASSIFICATION FOR
IDENTIFICATION OF
COMBATANTS

SIGNAL PROCESSING REQUIREMENTS

AGENDA

- TECHNOLOGY DRIVERS
- TI DEVELOPMENTS
  - ARCHITECTURES
  - COMPONENTS
  - ALGORITHMS
- PROJECTIONS FOR 1990

RADAR TECHNOLOGY DRIVERS

OPERATIONAL REQUIREMENTS:
(THE NEED)

- ACQUISITION OF HIGH RESOLUTION DATA BASES
- TARGET CLASSIFICATION, IDENTIFICATION, PRIORITIZATION
- MULTI-SENSOR DATA CORRELATION
- AUTOMATION FOR INCREASED EFFICIENCY OF DATA EXTRACTION
- OPERATION IN ADVERSE NATURAL AND MAN-MADE ENVIRONMENTS

RADAR TECHNOLOGY DRIVERS

CURRENT LIMITATIONS:
(THE PROBLEM)

- RADAR SYSTEMS LACK THE CAPACITY TO FULLY USE SENSOR DATA
- SIGNAL PROCESSING CAPACITY DEFICIENCIES ARE PRIMARILY DUE TO LIMITATIONS OF:

  THROUGHPUT
  MEMORY
  VERSATILITY

RADAR TECHNOLOGY DRIVERS

DEVELOPMENT NEEDS:

(THE SOLUTION)

- ARCHITECTURAL OPTIMIZATION OF STRUCTURES THAT PROVIDE:

  VERSATILITY (PROGRAMMABILITY)
  TECHNOLOGY COMPATIBILITY (REALIZABLE)
  GROWTH POTENTIAL (MEMORY/THROUGHPUT)
  FAULT TOLERANCE / MAINTAINABILITY

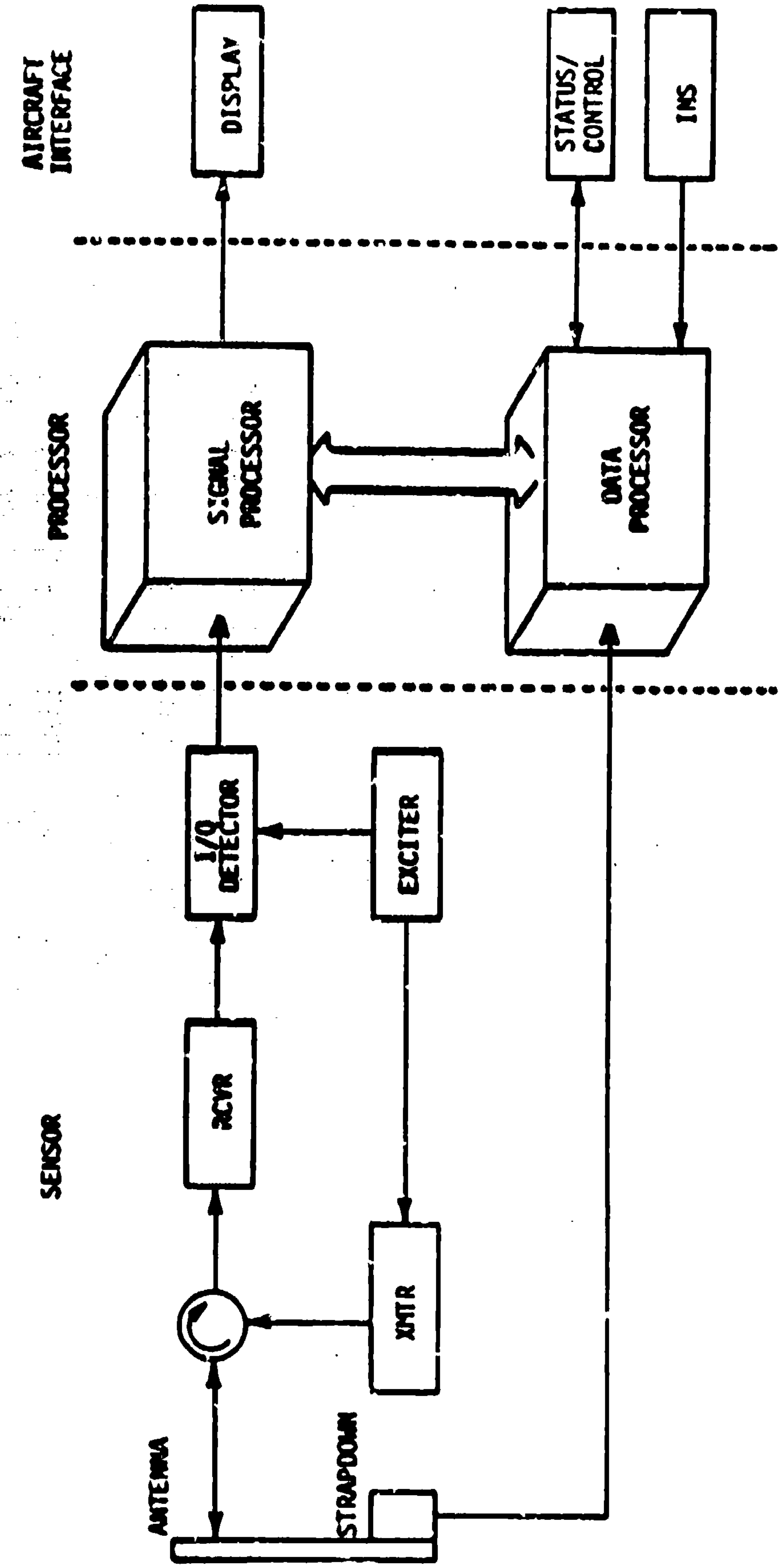
- COMPONENT DEVELOPMENT TO SUPPORT:

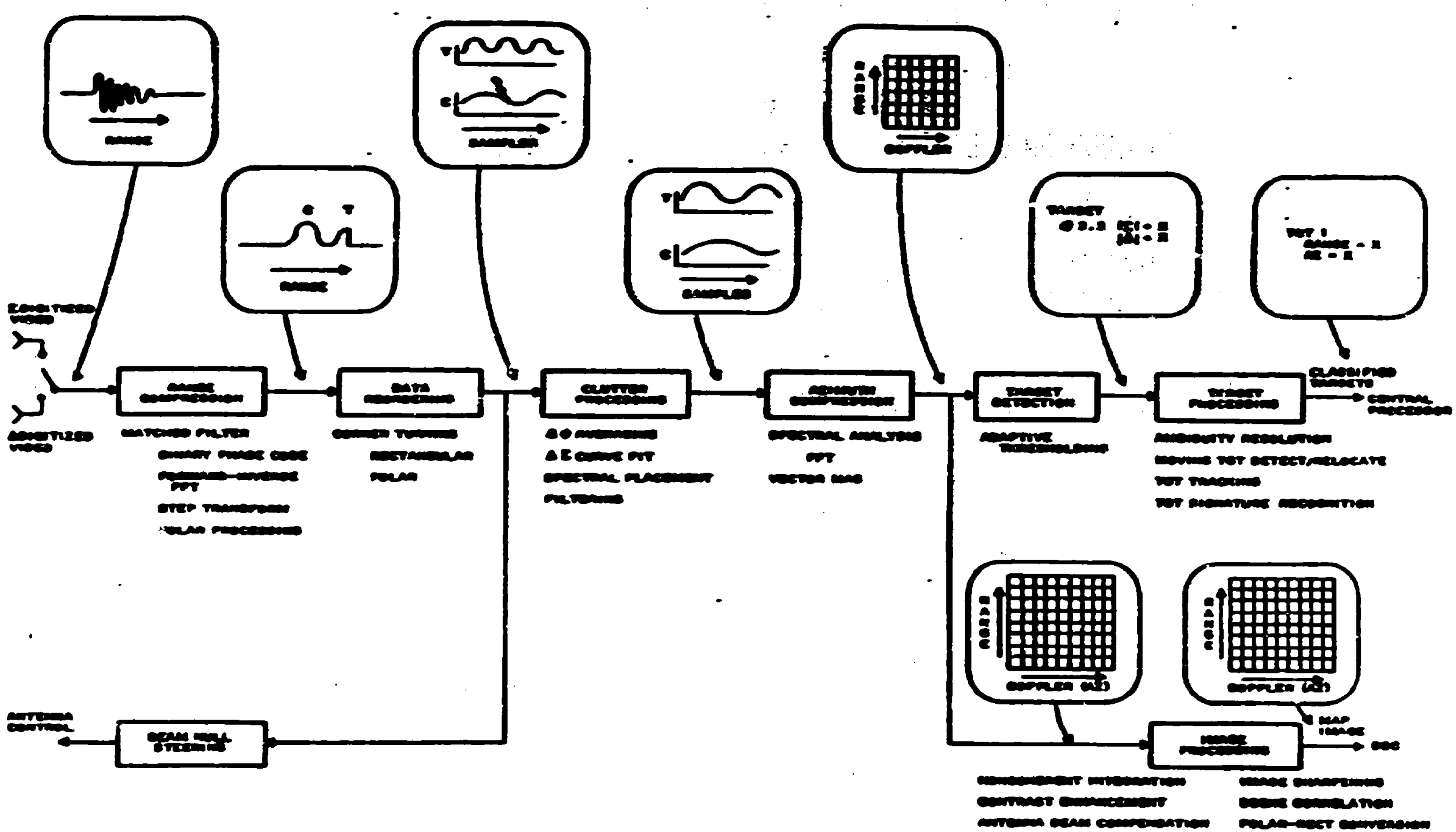
  MECHANIZATION OF ARCHITECTURAL REQUIREMENTS
  IMPROVED PERFORMANCE
  REDUCTION IN EQUIPMENT SIZE/COST

- ALGORITHM DEVELOPMENT TO:

  DEFINE SIGNAL PROCESSOR REQUIREMENTS
  OPTIMIZE EFFICIENCY OF SENSOR DATA EXTRACTION

RADAR SYSTEM BLOCK DIAGRAM





Radar Function Block Diagram

TI DEVELOPMENTS

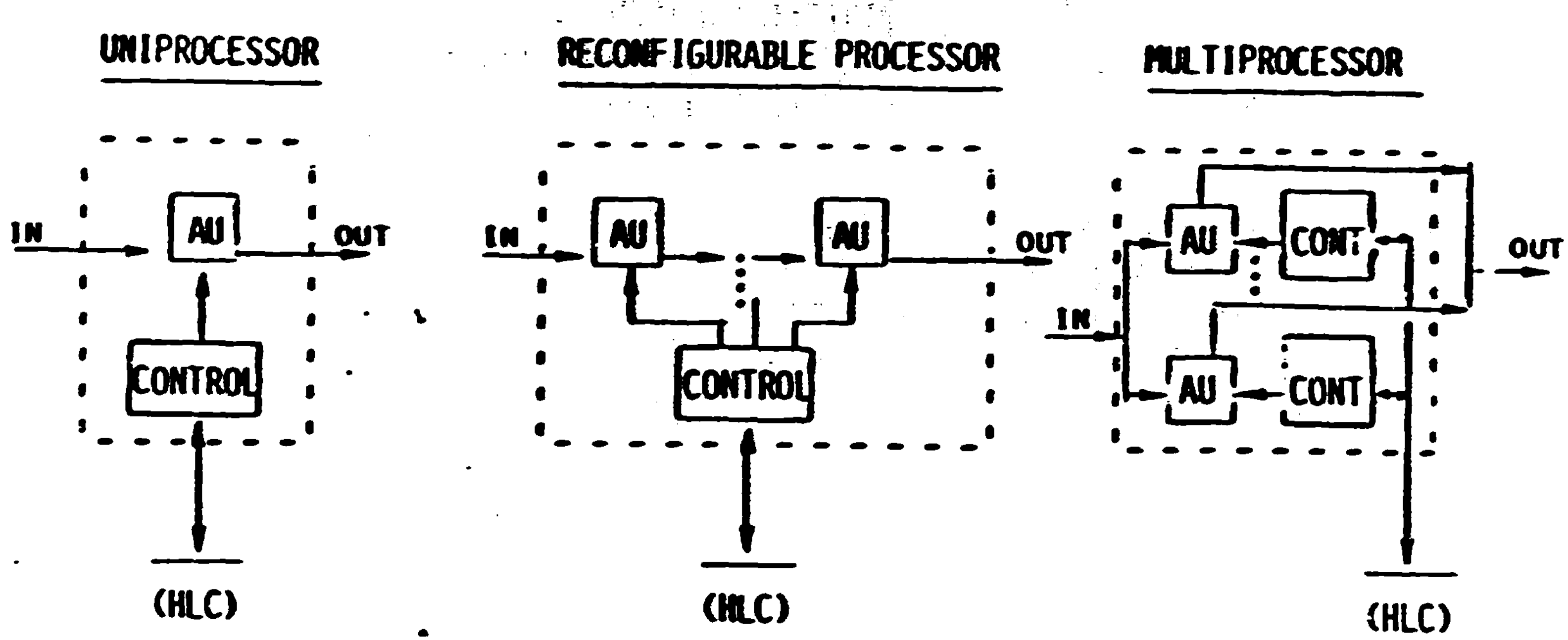
ARCHITECTURE:

RADAR PROCESSING

BLOCK STRUCTURED	DATA DEPENDENT
- FIXED SERIES OF ALGORITHMS APPLIED TO INDEPENDENT DATA SETS	- VARIED ALGORITHM SERIES APPLIED TO INDEPENDENT AND/OR COMMON DATA SETS
- ALGORITHMS IMPLEMENTED BY REPEATED APPLICATION OF "KERNEL" OPERATIONS ON DATA SETS	- ALGORITHM SERIES IS CONTROLLED BY INTERMEDIATE COMPUTATIONAL RESULTS
- EXAMPLES: FFT, FIR FILTER	- OPERATIONS ARE FUNDAMENTAL (+, -, x, ÷)

C.

ARCHITECTURAL CONFIGURATIONS



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ARCHITECTURE SUMMARY

UNIPROCESSOR

- \+ ARCHITECTURE DEMONSTRATED
- \+ ADEQUATE FLEXIBILITY
- \+ SATISFIES MULTIPLE APPLICATIONS THAT ARE $\leq$ THROUGHPUT CAPABILITIES
- \- ASSEMBLY LANGUAGE PROGRAMMING REQUIRED TO ACHIEVE MAXIMUM THROUGHPUT
- \- PERFORMANCE DEPENDENT ON DEVICE TECHNOLOGY USED
- \- PERFORMANCE DOES NOT SCALE (UP/DOWN)
- \- LACKS GROWTH POTENTIAL

RECONFIGURABLE PROCESSOR

- \+ ARCHITECTURE DEMONSTRATED
- \+ MOST EFFICIENT UTILIZATION OF PHYSICAL RESOURCES (PWR/WT/VOL)
- \+ GREATEST CAPACITY FOR HIGH THROUGHPUT APPLICATIONS
- \- LACKS HIGH DEGREE OF FLEXIBILITY FOR ALGORITHM CHANGE/GROWTH

MULTIPROCESSOR

- \+ ADEQUATE FLEXIBILITY
- \+ FAULT TOLERANT
- \+ INHERENT GROWTH CAPABILITY
- \- DIFFICULT TO PROGRAM/REPROGRAM (PARTITIONING OF TASKS)
- \- INEFFICIENT (OVERHEAD ASSOCIATED WITH INTERPROCESSOR COMMUNICATION)

RADAR SIGNAL PROCESSING

ARCHITECTURE SUMMARY:

- ARCHITECTURAL DIFFERENCES ARE DRIVEN BY VARYING DEMANDS FOR THROUGHPUT VERSUS FLEXIBILITY
- ALTERNATIVES

  #1 - FAMILY OF UNIPROCESSORS
  COVER PERFORMANCE RANGE
  UPWARD SOFTWARE COMPABILITY
  HOL AVAILABLE
  COMPATIBILITY WITH PRESENT AND FUTURE DEVICE TECHNOLOGY
  PROGRAMMABLE AT ALL LEVELS

  #2 - MULTIPROCESSOR
  EFFICIENT BUILDING BLOCK (VHSIC)
  EASY TO PROGRAM/REPROGRAM
  - FLEXIBLE RESOURCE ALLOCATION (DATA FLOW)
  NEAR LINEAR GROWTH POTENTIAL

  #3 - A COMBINATION OF STRUCTURES (FIXED/RECONFIGURABLE/PROGRAMMABLE) TO PROVIDE THE MINIMUM EQUIPMENT RESOURCES CONSISTENT WITH REQUIRED FLEXIBILITY AND PROVISIONS FOR FUTURE GROWTH

TI DEVELOPMENTS

COMPONENTS:

- THE CURRENT MILITARY POSTURE IS BASED ON MAINTAINING TECHNOLOGICAL RATHER THAN NUMERICAL SUPERIORITY
- THERE IS EVIDENCE THAT THE U.S. SUPERIORITY IN MILITARY IC'S IS ERODING
- THE MILITARY MARKET FOR IC'S HAS, OVER THE PAST DECADE, DECREASED TO 7% OF THE TOTAL BUSINESS
- THE MILITARY IS FINDING IT DIFFICULT TO DRIVE THE EVOLUTIONARY TECHNOLOGY DEVELOPMENT OF THE IC MARKET
- TO COUNTER THESE TRENDS, THE VHSIC PROGRAM WAS FORMED

VERY HIGH SPEED INTEGRATED CIRCUITS (VHSIC)

PURPOSE: TO MEET THE PRESENTLY DEFINED AND FUTURE MILITARY SYSTEM NEEDS FOR COMPLEX, HIGH SPEED SIGNAL PROCESSING FUNCTIONS

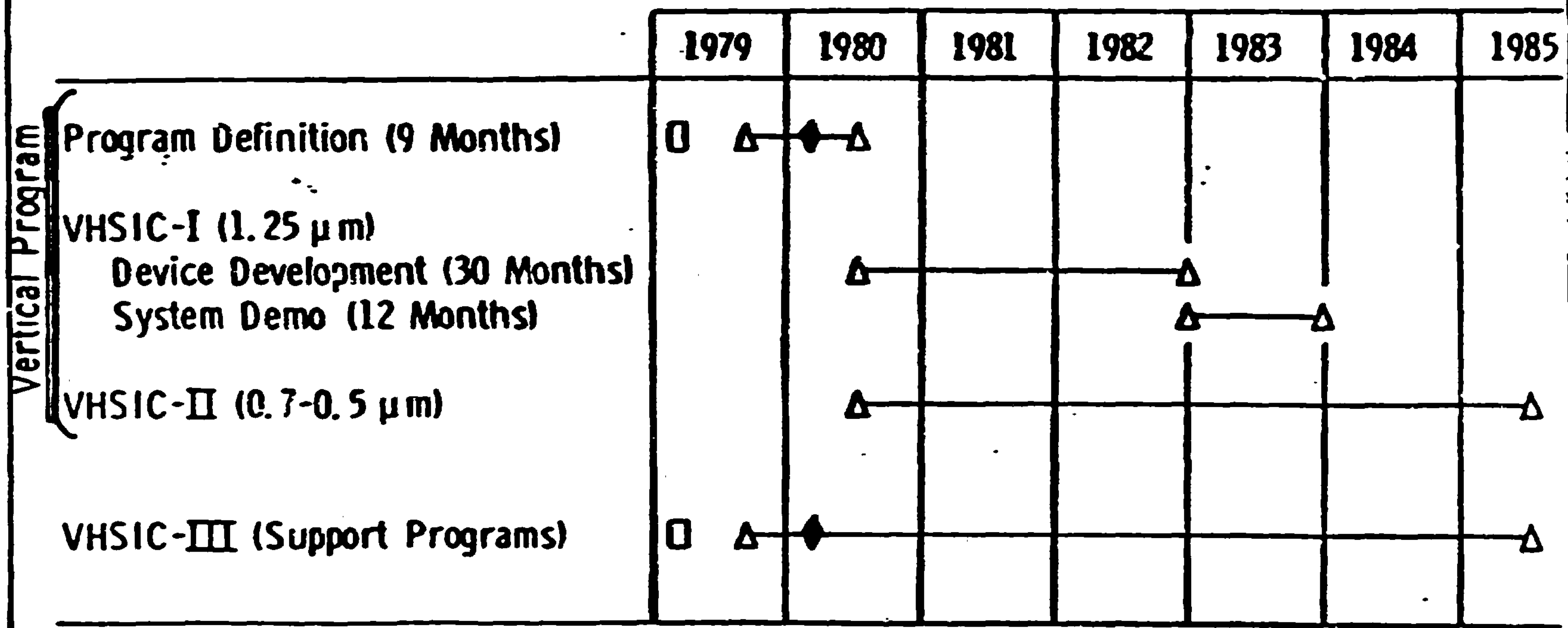
APPROACH: MULTIPHASE VERTICAL PROGRAMS

- PHASE "0" -PROGRAM DEFINITION
- PHASE "I" -DEVICE/BRASS BOARD DEVELOPMENT (1.25UM)
- PHASE "II" -DEVICE DEVELOPMENT/SYSTEM DEMO (0.7-0.5UM)

SUPPORT PROGRAM

- PHASE "III"

DoD-VHSIC PROGRAM PLAN



□ - RFP

EMERGING DIGITAL TECHNOLOGY

- VERY HIGH SPEED INTEGRATION (VHSI)
  - PROVIDE STEP IN FUNCTIONAL CAPABILITY FOR MILITARY APPLICATIONS OF INTEGRATED CIRCUITS
  - DEVELOPMENT OBJECTIVES:

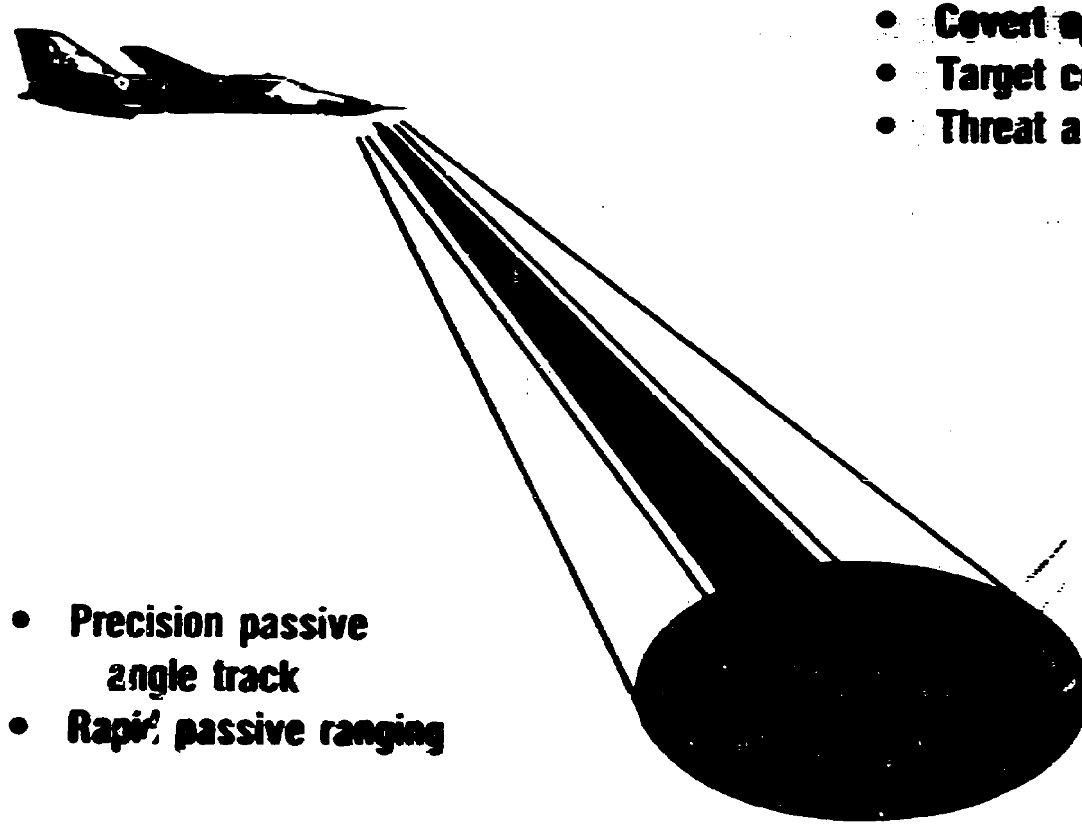
	1979	1983	1986
GEOMETRY	5 UM	1.25 UM	0.5 UM
<u>DENSITY</u> (PER DEVICE)	6K GATES 64K BITS	50K GATES 256K BITS	150K GATES 1M BITS
<u>SPEED</u> (PER GATE)	12NS	2.4NS	0.6NS

TI DEVELOPMENTS

ALGORITHMS:

- PASSIVE/ACTIVE
  - MSLS
  - PA^3S
- TARGET CLASSIFICATION
  - PROFILE
  - RAMTAC
  - ASMIR
- DMA DATA BASE
  - AETMS

PA³S
AIR-TO-GROUND



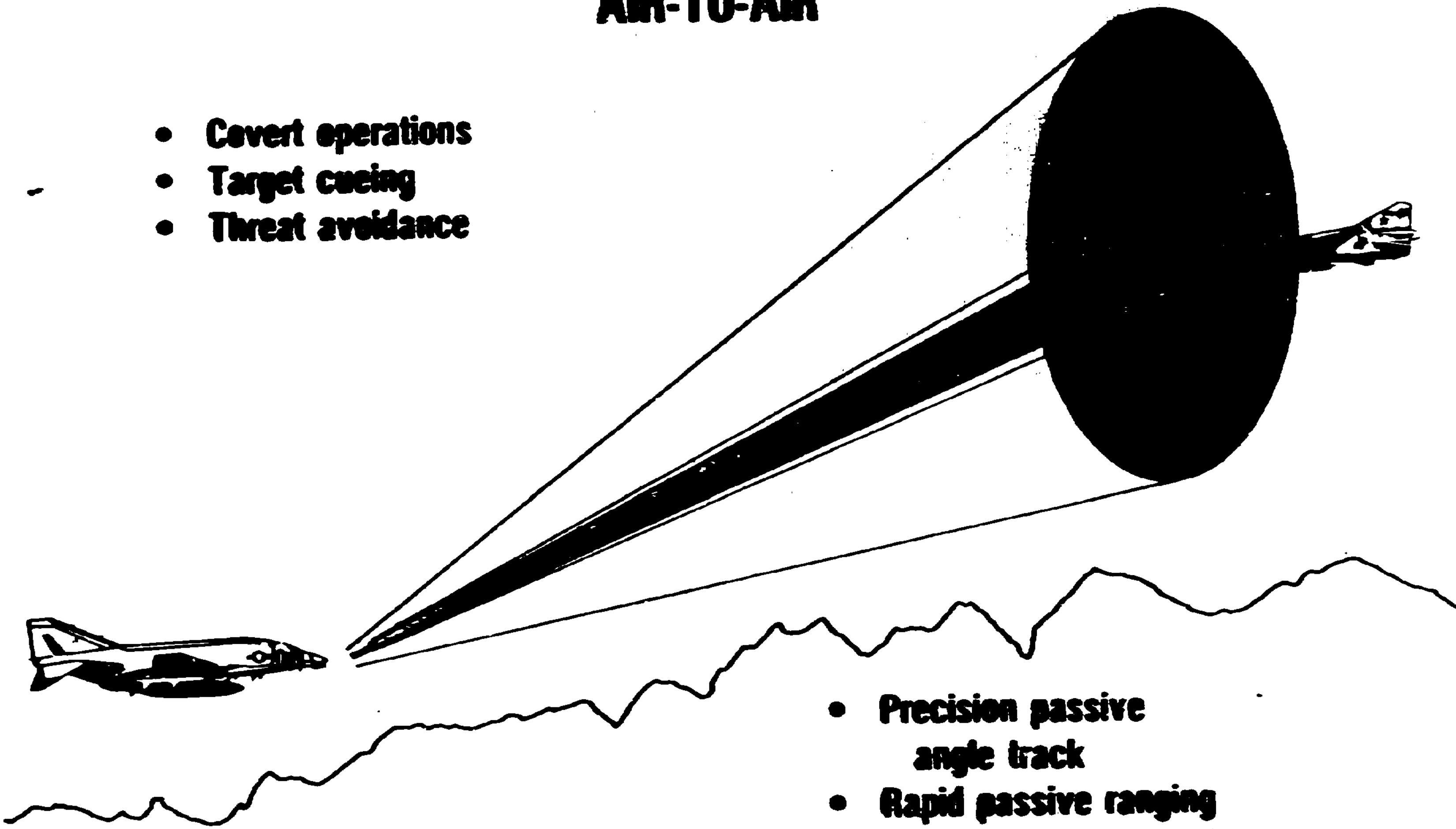
- Covert operations
- Target cueing
- Threat avoidance

- Precision passive angle track
- Rapid passive ranging

01/29/88 CK 81-831

PA3S
AIR-TO-AIR

- Covert operations
- Target cueing
- Threat avoidance



- Precision passive angle track
- Rapid passive ranging

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PROJECT PROFILE

HAVE BEEN FOUR PHASES:

I.	GROUND BASED TESTS -- SAN DIEGO	8/76
	O LABORATORY PROCESSING OF DATA	
II.	AIRBORNE TESTS -- NORFOLK, SAN DIEGO	1/77
	O LABORATORY PROCESSING OF DATA	
III.	AIRBORNE TESTS -- SAN DIEGO	3/77
	O IN-FLIGHT PROCESSING OF DATA	
	O DATA-LINK TO A GROUND BASE	
IV.	AIRBORNE TESTS -- MEDITERRANEAN	6/78
	O SOVIET SHIP TARGETS	
	O OPERATIONAL ENVIRONMENT	
	O DEMONSTRATE LONG RANGE (>100 NMI)	
	O DEMONSTRATE FASTER PROCESSING (5 SECONDS)	

PROJECT PROFILE

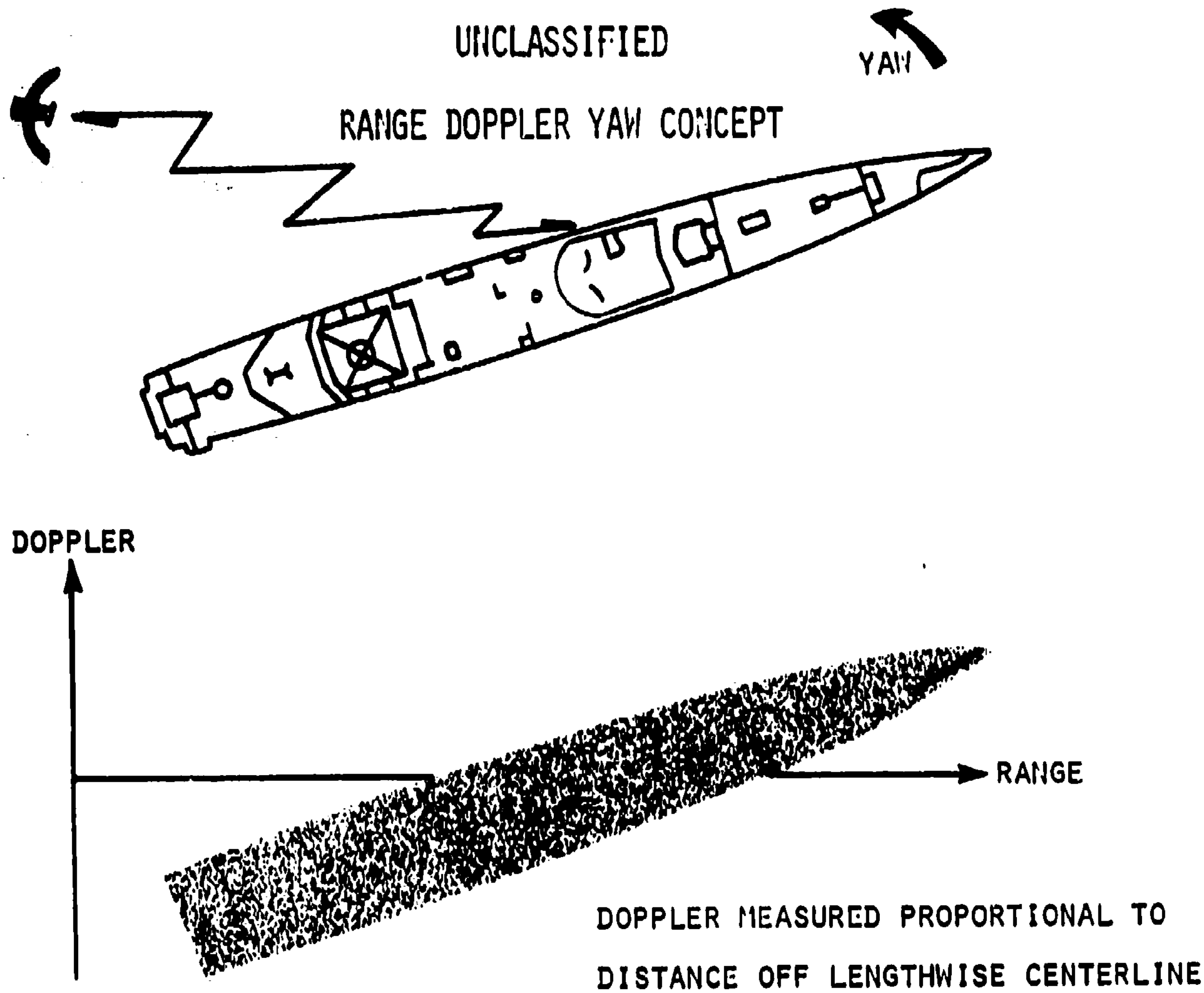
OBJECTIVE:
- O CLASSIFY NON-EMITTING SHIPS
  - O OPEN OCEAN
  - O ALL WEATHER
  - O DAY/NIGHT
  - O LONG RANGE (>100 NMI)

APPROACH:
- O SYNTHETIC APERTURE RADAR TECHNIQUES

APPLICATION:
- O OVER-THE-HORIZON TARGETING
- O OCEAN SURVEILLANCE

UNCLASSIFIED

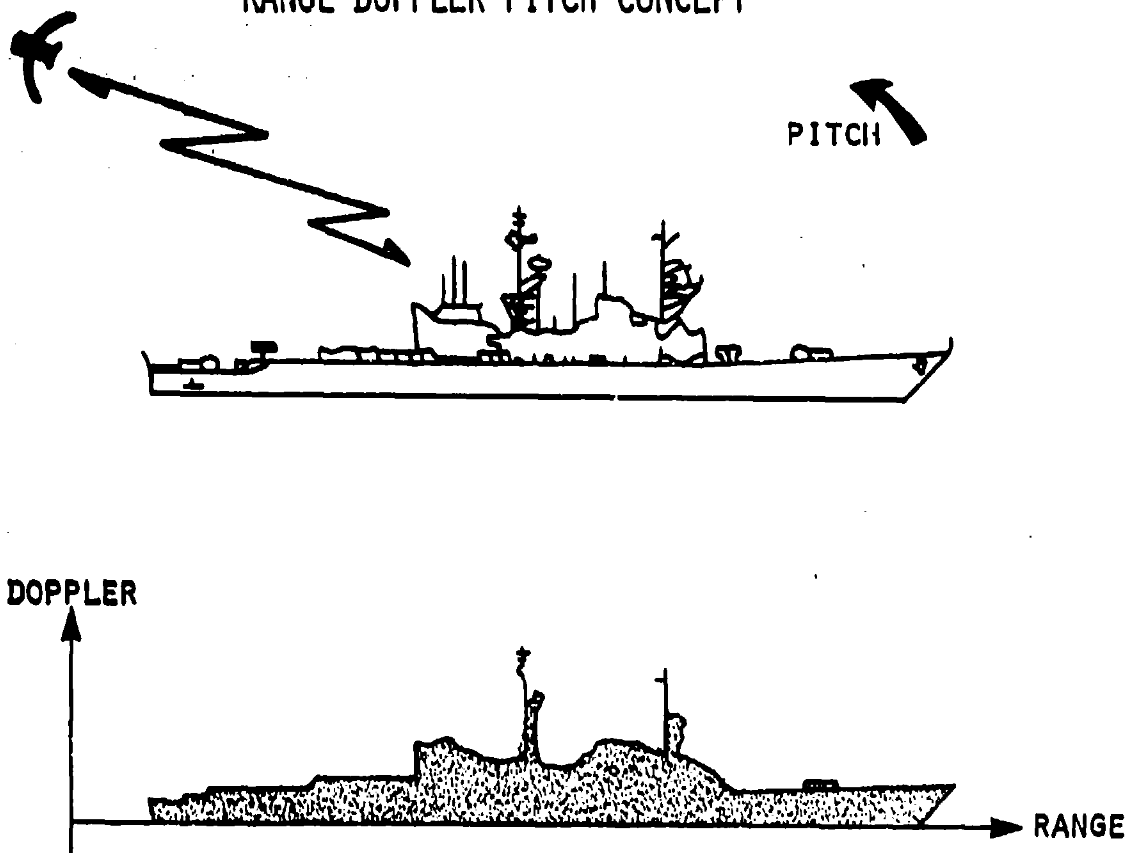
RANGE DOPPLER YAW CONCEPT



UNCLASSIFIED

UNCLASSIFIED

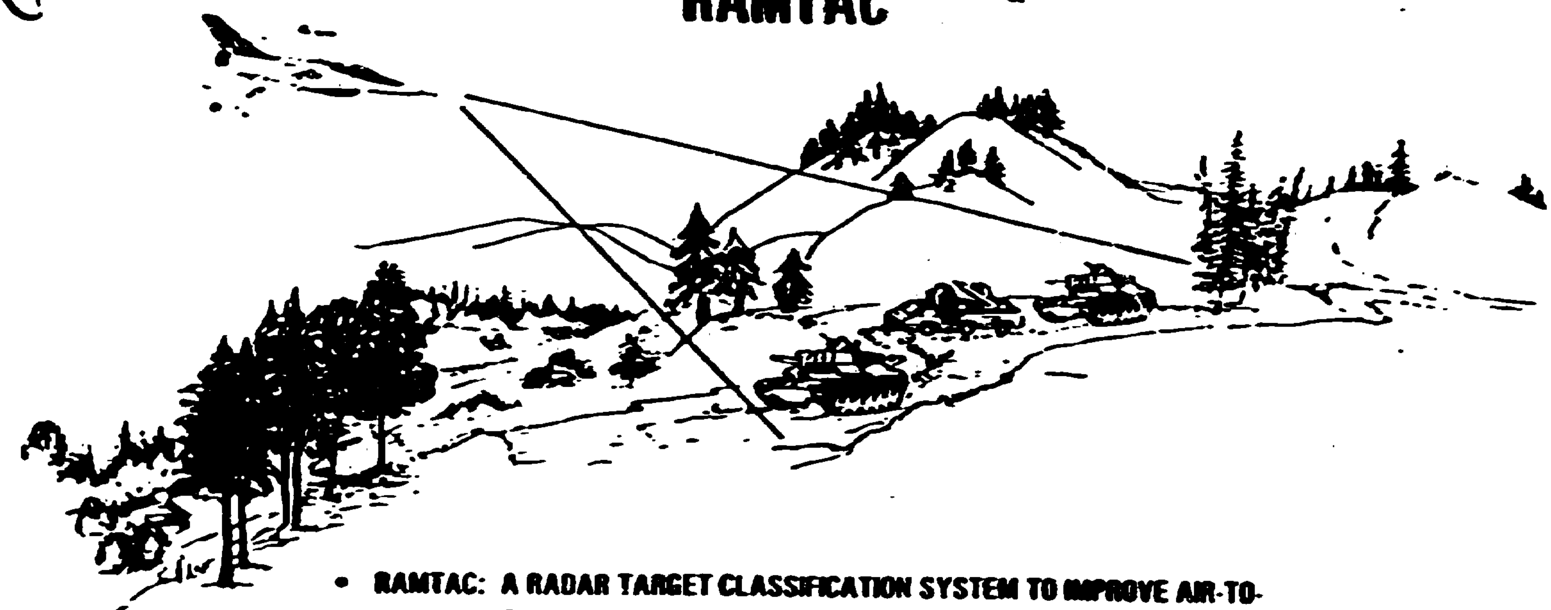
RANGE DOPPLER PITCH CONCEPT



DOPPLER MEASURED BY RADAR
PROPORTIONAL TO HEIGHT

UNCLASSIFIED

RAMTAC



- RAMTAC: A RADAR TARGET CLASSIFICATION SYSTEM TO IMPROVE AIR-TO-GROUND SURVEILLANCE AND ATTACK CAPABILITY AGAINST ENEMY VEHICLES
  - PHASE ZERO
    - INITIAL SYSTEM CONCEPT STUDY
    - VERIFY FEASIBILITY OF CONCEPT
  - PHASE ONE
    - ROOFTOP DEMONSTRATION TEST
    - ESTABLISH TECHNICAL FEASIBILITY
  - PHASE TWO
    - FLIGHT TEST DEMONSTRATION
    - ESTABLISH TECHNICA: UTILITY

RAMTAC

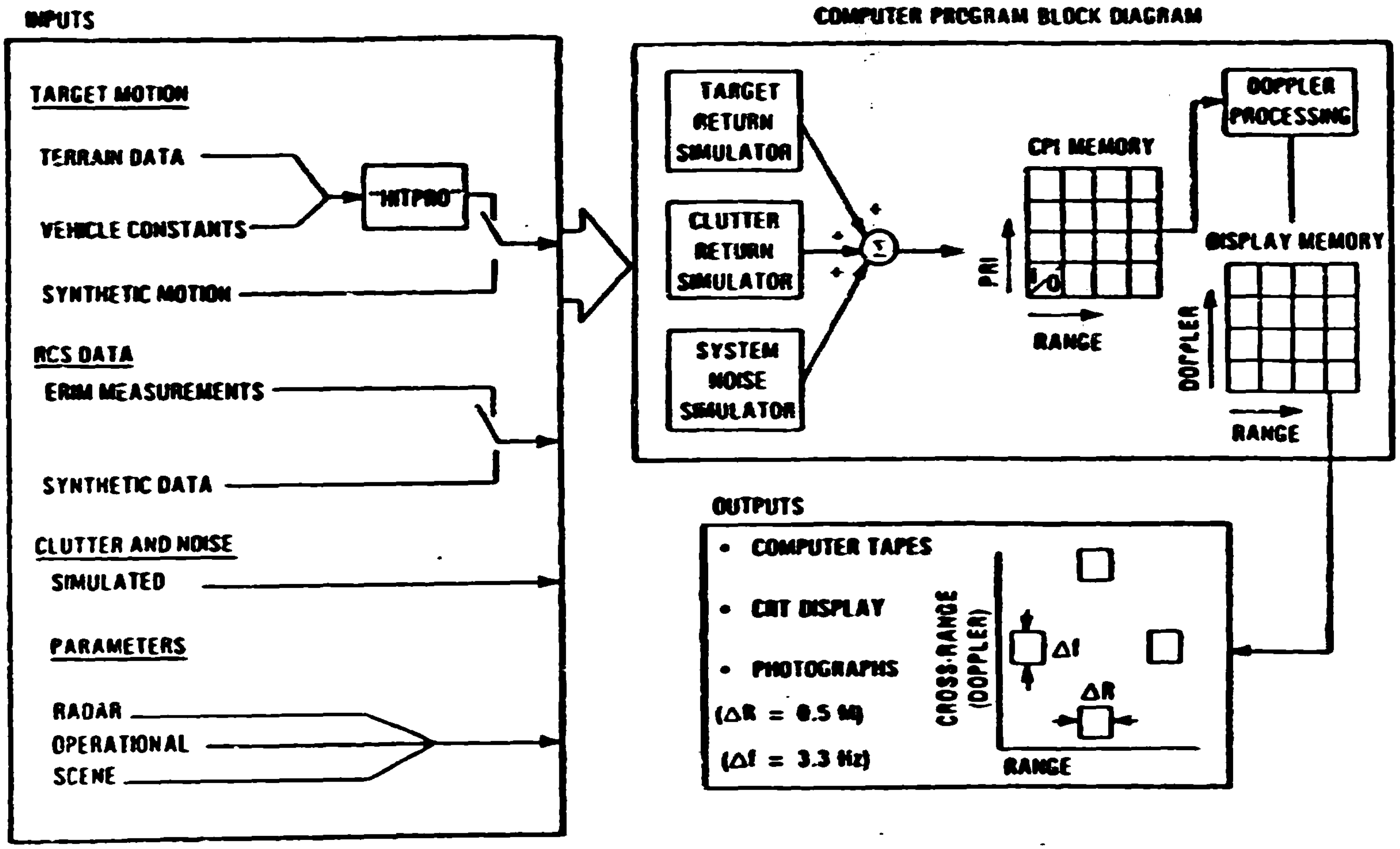
OBJECTIVE

- EVALUATE CONCEPT FOR CLASSIFYING GROUND MOVING TARGETS IN ADVERSE WEATHER
- DEVELOP CLASSIFICATION SYSTEM TO DISTINGUISH:
  - HIGH-PRIORITY TARGETS (SELF-PROPELLED AA GUNS, MOBILE SAMS, ...)
  - PRIORITY TARGETS (TANKS, APCS, ...)
  - LOW-PRIORITY TARGETS (JEEPS, CIVILIAN VEHICLES, ...)

NEED

- CLASSIFICATION OF GROUND MOVING TARGETS HAS NOT BEEN ADEQUATELY DEVELOPED - A TRUE ALL-WEATHER EFFECTIVE SYSTEM DOES NOT CURRENTLY EXIST
- AIR FORCE OPERATIONAL STUDIES INDICATE GMT CLASSIFICATION IS A HIGH PAYOFF AREA

COMPUTER SIMULATION: DEVELOPED TO GENERATE RAMTAC PSEUDO-IMAGES AND AID IN ANALYTICAL STUDIES

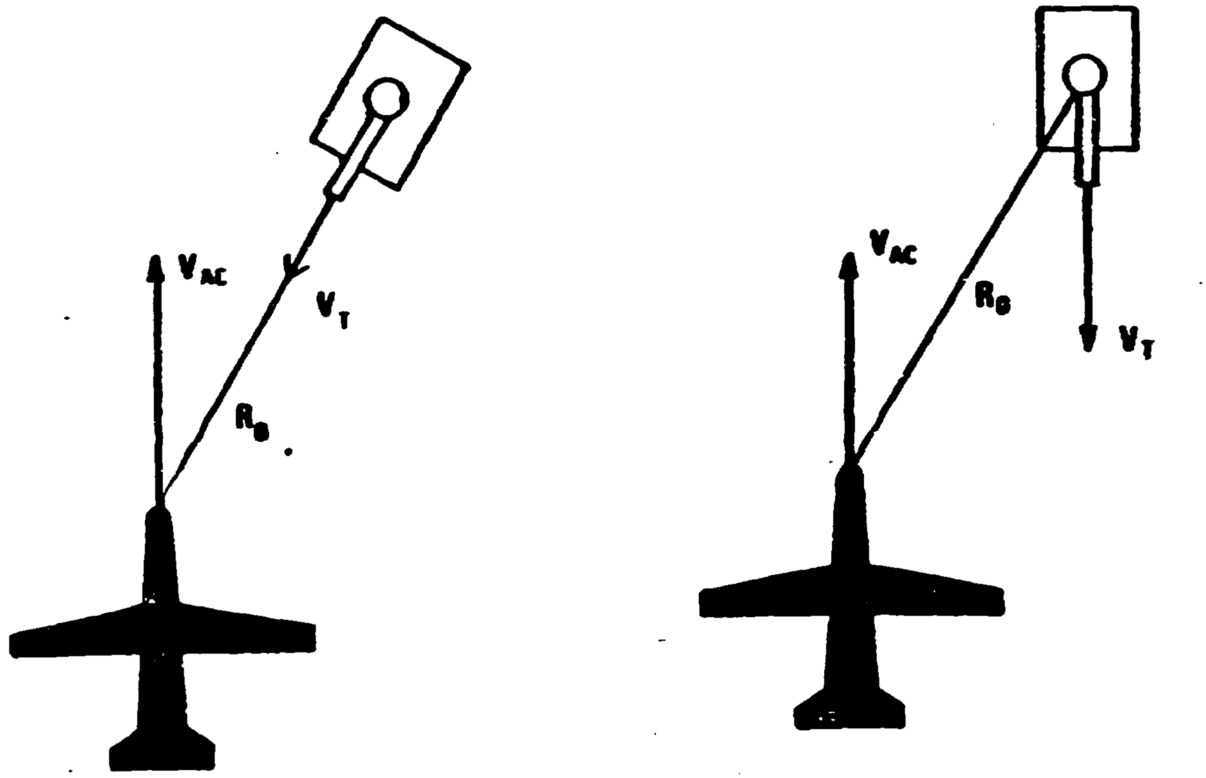


SCENARIOS

PARAMETERS

- SQUINT ANGLE = 30°
- R_B = 25KM
- V_{AC} = 200 M/SEC, H_{AC} = 50M

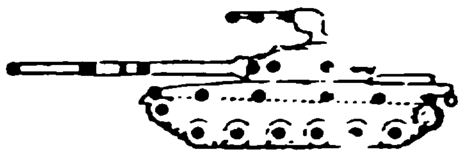
RADIAL APPROACH — 30° APPROACH



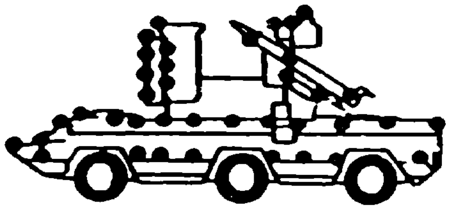
RAMTAC IMAGES OF T-72 TANK AND SA-8 SAM

(RADIAL APPROACH, PITCH RATE = -200 MRAD/SEC)

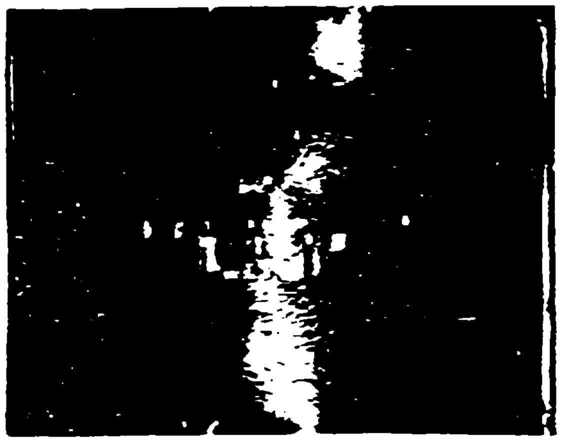
T-72 TANK (SYNTHETIC) RCS



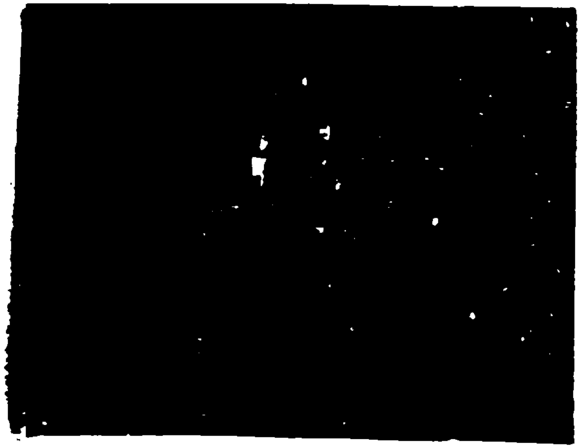
SA-8 SAM (SYNTHETIC) RCS



RAMTAC IMAGE OF T-72



RAMTAC IMAGE OF SA-8



OBJECTIVES

- DEMONSTRATE FEASIBILITY OF AETMS WITH FLYABLE BRASSBOARD
- EVALUATE AETMS IN THE FOLLOWING AIRCRAFT OPERATIONAL APPLICATIONS
  - NAVIGATION
  - NIGHT OR INSTRUMENT FLIGHT RULE FLYING
  - WEAPON DELIVERY: LOW-LEVEL ATTACK
  - TERRAIN AVOIDANCE/TERRAIN FOLLOWING
  - THREAT AVOIDANCE
  - TARGET LOCATION
  - FLIGHT PATH CONTROL; MANUAL AND AUTOMATIC
- DEMONSTRATE REAL-TIME SENSOR CORRELATION WITH THE TEXAS INSTRUMENTS MULTIPURPOSE RADAR/MISSILE SITE LOCATION SYSTEM (TIMPR/MSLS)

1980 PLANS

TASKS

- ESTABLISH DEMONSTRATION AETMS SYSTEM REQUIREMENTS AND SPECIFICATIONS
  - MISSION/OPERATIONAL ANALYSIS
  - DATA BASE
  - DATA PROCESSING AND DISPLAY GENERATION
- DESIGN PROTOTYPE AETMS HARDWARE AND SOFTWARE
- IMPLEMENT SYSTEM DESIGN
- INTEGRATION AND TEST IN TI AIRCRAFT
- FLIGHT TEST AND DEMONSTRATION

MILESTONES

MILESTONES	DATE
• SYSTEM REQUIREMENTS AND SPECIFICATIONS COMPLETE	7/80
• DESIGN COMPLETE	8/80
• COMPLETE SYSTEM FAB	10/80
• BEGIN INTEGRATION AND TEST	11/80
• DEMONSTRATION	12/80

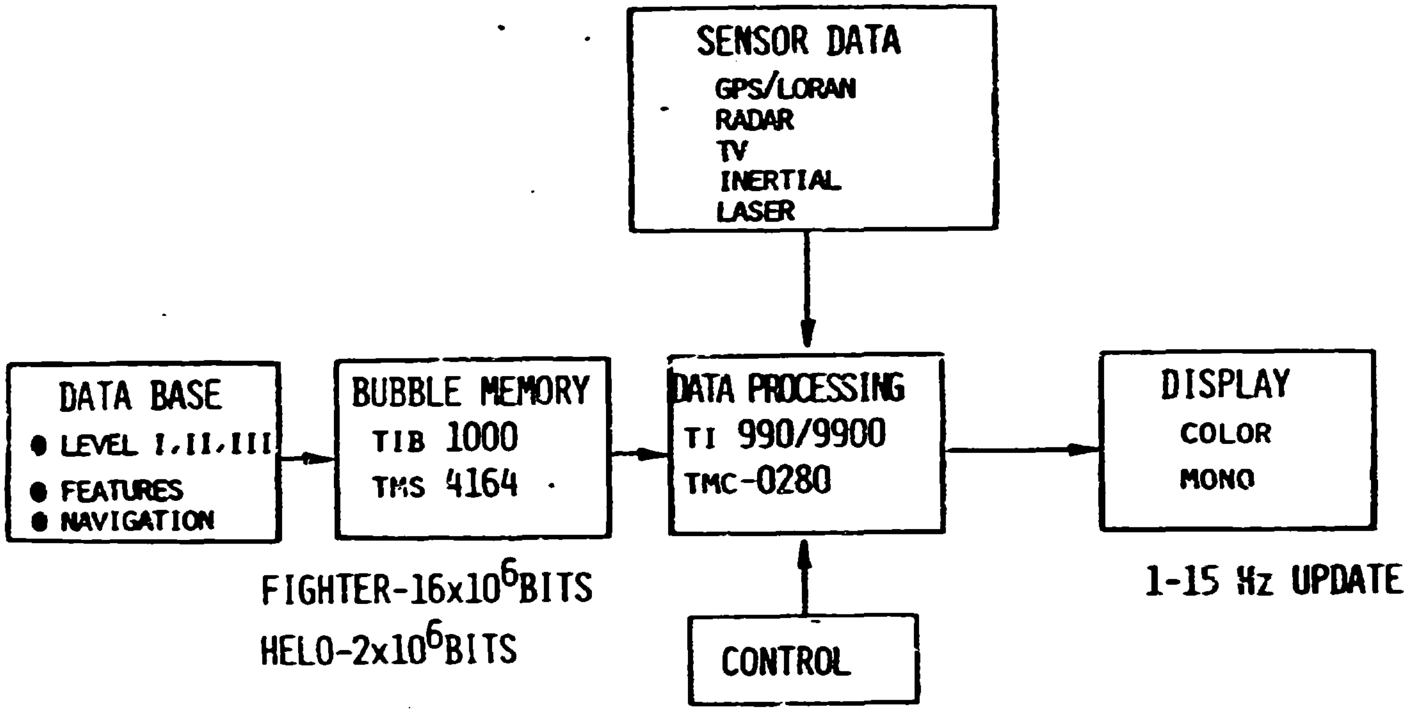
AETMS PERFORMANCE GOALS

AREA STORED:	10,000 SQUARE MILES
ELEVATION ACCURACY:	± 30 FEET
UPDATE RATE:	15 Hz. MAX
DISPLAY:	16 COLORS / 16 GRAY SHADES (MONO)
RECOGNITION:	256 LINES X 256 PIXELS
SENSOR INPUTS:	GPS, RADAR, FLIR, LORAN INERTIAL

MODES:

- STATIC MAP - VEHICLE MOVES
- DYNAMIC MAP - VEHICLE STATIC
- PERSPECTIVE
- PLANVIEW

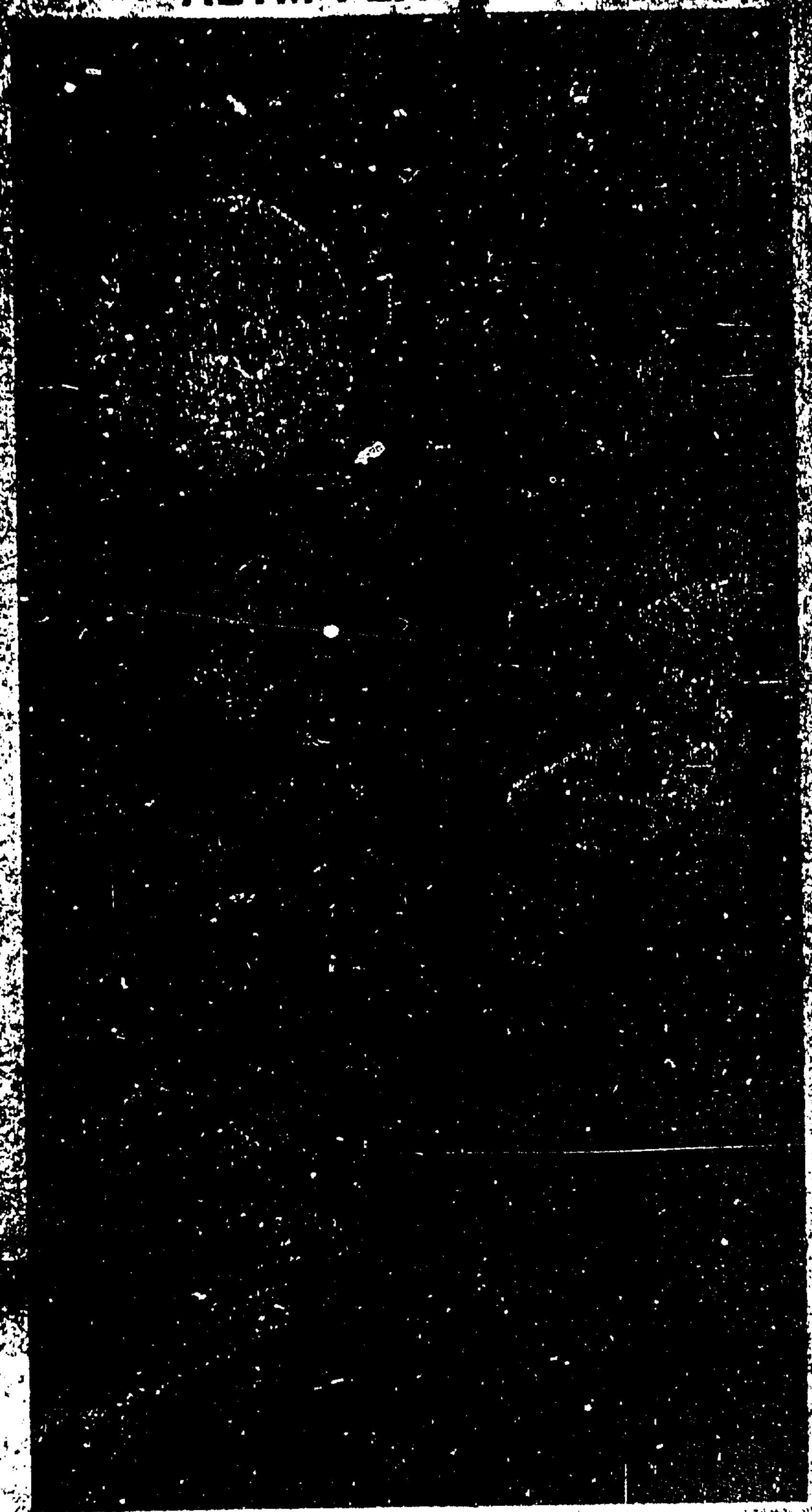
ELECTRONIC TERRAIN MAP
FUNCTIONAL DESCRIPTION



- DEFENSE MAPPING AGENCY HAS DIGITIZED THE WORLD
- MANMADE FEATURE DATA BEING ADDED TO DMA DATA BASE
- DATA BASE COMPRESSION

RADAR ADVANCED DEV

AETM PLAN VIEW



EQUIPMENT GROUP

10/25/79 01-931

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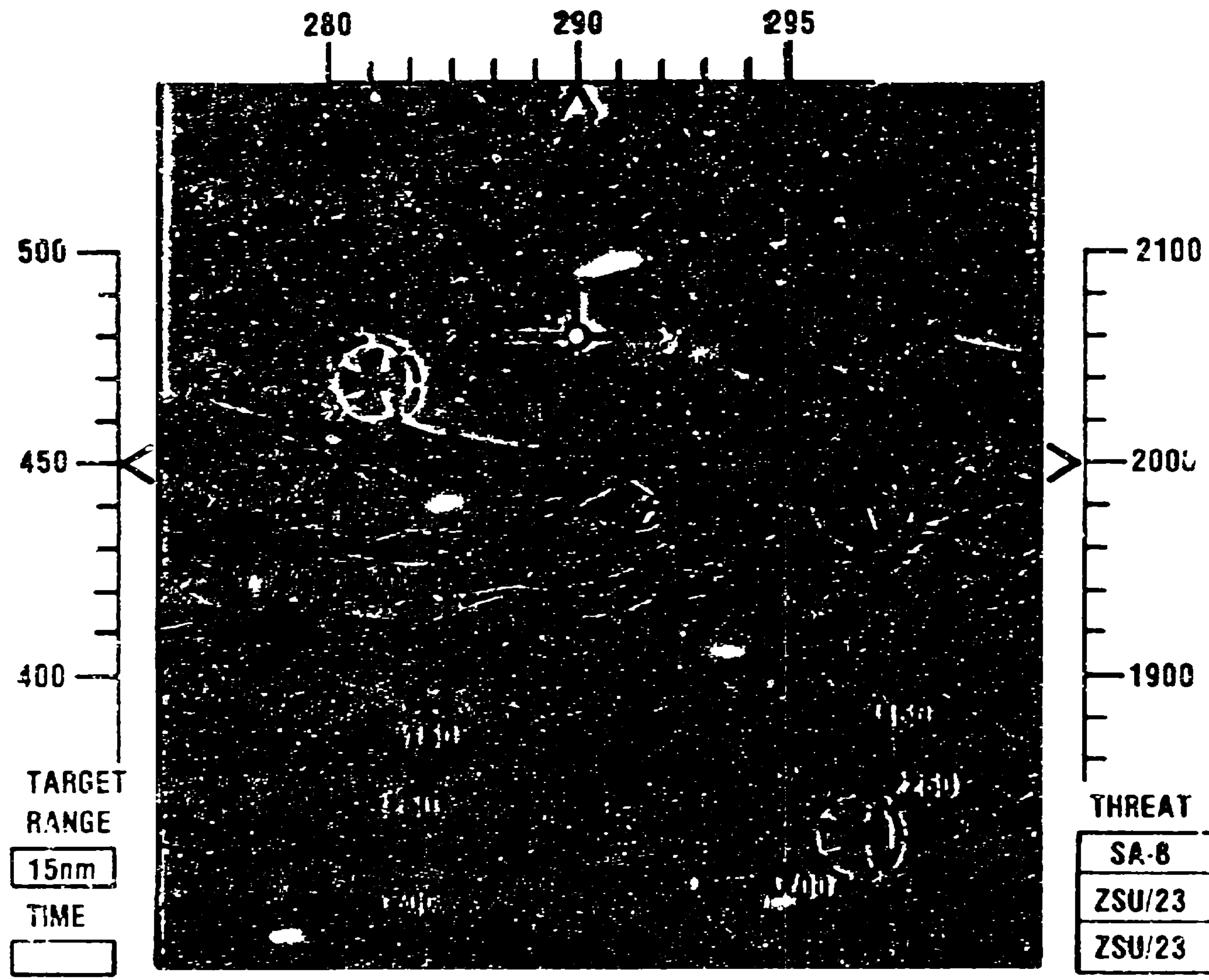
AETM PERSPECTIVE DISPLAY



THREAT	RANGE	AZ
SA-8	25	25L
ZSU/23	25	25R
ZSU/23	7	50R

PROJECTIONS FOR THE 1990'S

- ADVANCED TECHNOLOGY DEVELOPMENT (VHSIC AND PHASED ARRAYS) WILL SIGNIFICANTLY ENHANCE OPERATIONAL CAPABILITY
- MULTIPLE PRIMARY RADAR MODES WILL OPERATE ON A INTERLACED TIME-LINE BASIS
- OPERATION OF PRIMARY RADAR RESOURCES WILL BE AUTOMATED (PARTICULARLY LOW LEVEL HARMONIZATION) - OPERATOR WILL CANCEL/CONTINUE/REINITIATE SYSTEM OPERATION
- TARGET IDENTIFICATION/CLASSIFICATION/PRIORIZATION WILL BE:
    - AUTOMATED
    - OPTIMIZED FOR MISSION
- PRIMARY RADAR RESOURCES WILL PLAY A LARGER (E.G., SPW) ROLE IN DELIVERY OF LOW COST WEAPONS
- STORED DATA BASES, (DMA, RADIOMETRIC, ETC.), POWER MANAGEMENT (ADAPTIVE) AND VERSATILE WAVEFORM GENERATION (CODED) WILL ENHANCE COVERTNESS

PROJECTIONS FOR THE 1990'S (CONTINUED)

- INTEGRATED DISPLAY SYSTEM WILL PROVIDE A STANDARDIZED INTERFACE TO ALL SENSORS (IMAGE PROCESSING FUNCTION) FUSION OF DATA FROM MULTIPLE SENSORS (I.E., RADAR, IR) WILL INCREASE PROBABILITY OF TARGET RECOGNITION

- FORECAST REDUCTION OF RESOURCES (BASED ON CONSTANT 1980 PERFORMANCE LEVEL)

SIZE	0.25
POWER	0.10
WEIGHT	0.25

APPENDIX D

U. S. DEFENSE MAPPING AGENCY DATA

APPENDIX D

U.S. DEFENSE MAPPING AGENCY DATA

The U.S. Defense Mapping Agency has assembled digital map data for certain areas of the earth. Their source material includes aerial photographs, topographic charts, remotely sensed imagery, and ground truth information. DMA data is intended for such applications as static map generation, radar landmass simulation, flight simulation, and cockpit displays for high-speed low flying aircraft.

The DMA supplies two categories of data: terrain and culture files. A terrain file is an array of elevation values for a region of the earth. The sampling interval of the terrain is a function of latitude (see Table D-1). The elevation array for each terrain region is stored on magnetic tape at two different resolutions. A culture file holds the descriptions of man-made and ecological surface features within a given terrain region. Most feature types are represented by a polygonal boundary and a coded description. However, the locations of some features such as bridges, dams, walls, and pipelines are given as polygonal lines, while others such as tall buildings and water towers are given as points.

Culture polygons are assigned both a predominant surface material and a more specific surface description. The 13 general categories of surface materials are given in Table D-2. As an example, the general category assigned to a culture polygon may be trees. The particular subclasses under this heading are orchard, deciduous forest, conferous forest, evergreen, and mixed forest. Each tract of trees is given a predominant tree height.

TABLE D-1 DMA TERRAIN DATA INTERVALS

Latitude	Level 1 Latitude by Longitude	Level 2 Latitude by Longitude
0° - 50° N-S	3 by 3 sec	1 by 1 sec
50° - 70° N-S	3 by 6 sec	1 by 2 sec
70° - 75° N-S	3 by 9 sec	1 by 3 sec
75° - 80° N-S	3 by 12 sec	1 by 4 sec
80° - 90° N-S	3 by 18 sec	1 by 6 sec

TABLE D-2 THIRTEEN DMA PREDOMINANT MATERIAL TYPES

1. Metal
2. Part Metal
3. Stone/Brick
4. Composition
5. Earthen Works
6. Water
7. Desert/Sand
8. Rock
9. Asphalt/Concrete
10. Soil
11. Marsh
12. Trees
13. Snow/Ice

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

A/D	analog-to-digital
AAH	Advance Attack Helicopter
ADI	automatic direction indicator
AETMS	Airborne Electronic Terrain Map System
AGC	automatic gain control
AIDS	Advanced Integrated Display System
AL	Avionics Laboratory
AMRL	Air Force Material Research Laboratory
ARLMS	analog radar landmass simulator
AWAVS	Aviation Wide Angle Visual System
CCD	charge-coupled-device
CCTV	Closed Circuit Television
CEP	circular error probability
CFAR	constant false alarm rate
CID	charge-injection-device
CIG	computer image generator
CMS	camera model system
CPU	central processing unit
CRT	cathode ray tube
CTS	Cartographic Technical Squadron
D/A	digital-to-analog
DAIS	Digital Avionic Information System
DBS	Doppler Beam Sharpening
DDB	digital data base
DDBTP	Digital Data Base Transformation Program
DF	direction finding
DIG	digital image generator
DMAAC	Defense Mapping Agency, Aerospace Center
DRG	Digital Raster Graphics
DRLMS	digital radar landmass simulator
DSC	digital scan converter
DVRS	Digital Video Recording System
E-O	electro-optical

EAR	electronically agile radar
ECCM	electronic counter-countermeasures
ECM	electronic countermeasures
EVS	Electro-Optical Viewing System
EW	electronic warfare
FDL	Flight Dynamics Laboratory
FET	field effect transistor
FLIR	forward-looking infrared
FLOLS	Fresnel Lens Optical Landing System
FLR	forward-looking radar
FOV	field of view
FSS	flying-spot scanner
FY	fiscal year
GMTI	ground moving target indication
GMTT	ground moving target track
GPS	Global Position System
HDD	heads-down display
HMD	helmet-mounted display
HSD	horizontal situation display
HUD	head-up display
IF/FC	Integrated Flight/Fire Control
IF/WC	Integrated Flight/Weapon Control
IM	Inertial Measurement
INS	Inertial Navigation System
IR	infrared
IRST	infrared search and track
ISIT	Intensified Silicon Intensified Target
IVC	International Video Corporation
JTIDS	Joint Tactical Information Display System
LAMARS	Large Amplitude Multimode Aerospace Simulation
LANTIRN	Low-Altitude Navigation Targeting Infrared for Night
LED	light-emitting diode
LLLTV	low-light-level television
LOAL	lock on after launch
LOTAWS	Laser Obstacle and Terrain Avoidance Warning System

LPI	low probability intercept
LSAD	left situation advisory display
LSB	least significant bit
LSIG	Laser Scanner Image Generator
LST	laser spot tracker
LWR	laser warning receiver
MFD	multifunction display
MIIR	missile imaging infrared
MOS	metal oxide semi-conductor
MRI	Monopulse Resolution Improvement
MSLS	Missile Site Location System
MTF	modulation transfer function
MTI	moving target indication
MTT	moving target tract
MYSTIC	Multispectral Target Cuing
NOE	nap of the earth
NTEC	Naval Training Equipment Center
OAS	Orbital Aeroflight Simulator
PA^3S	Passive Active Acquisition Avoidance System
PbO	Lead Oxide
PHS	probe height sensor
PMT	Photo-Multiplier Tube
PPI	plan position indicator
PRF	pulse repetition frequency
RAMTAC	Radar Target Classification System
RGB	red, green, blue
RHAWS	Radar Homing and Warning Systems
RSAD	right situation advisory display
RWM	radar warning mode
SAR	synthetic aperture radar
SCAMP	Scanned Motion Picture
SCR	Silicon Control Rectifier
SDA	Silicon Diode Array
SIT	Silicon Intensified Target
SNR	signal-to-noise ratio

SOTA	state of the art
SOW	Statement of Work
SPO	Simulator Procurement Office
STC	sensitivity time control
TA	terrain avoidance
TF	terrain following
TI	Texas Instruments, Inc.
TOW	tracking, optical, wire
TSIS	Total System Integration Simulator
TV	television
UTC	United Technologies Research Center
VAMP	Variable Anamorphic Motion
VHSIC	very high speed integrated circuits
VSD	vertical situation display
VTR	video tape recorder
WSO	Weapon System Operator
ZMN	zero memory nonlinearity

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